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SOME FACTORS AFFECTING THE OPERATION OF INCANDESCENT LAMPS

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INTRODUCTION

Most of the present-day light sources result from an attempt to convert electrical energy into light, which means to convert electrical energy into radiant energy within the visible spectrum. The final problem is to produce a light source satisfactory for the purpose at hand and, in general, with as high efficiency in lumens per watt as possible; that is, to obtain as many lumens as possible per watt input. For some lamps, the criterion is not to produce as many lumens as possible, but to produce as much light in a particular direction as possible. This is true in the case of the projection lamp. Some of these lamps have two sets of coils, both in a plane, and one directly behind and opposite the space between the coils so as to produce as uniform source of light as possible and as nearly as possible filling the space with light.

ENERGY LOSSES OF INCANDESCENT LAMPS

In any conversion from one type of energy to another, there are certain losses that can not be avoided even with no restrictions on the method—in this case the type of radiator to be used. Such losses may or may not be increased when the added condition is imposed of obtaining a good light source. The entire electrical input into any raditor is lost by radiation from the radiator itself, from the connections, by conduction of the leads and by conduction and convection of the surrounding gas. Some of the radiated energy may be in the very long wavelength part of the spectrum since the part of the equipment that is doing the radiating may be at a temperature of only 100 to 200°C. above the surroundings. This low-temperature radiant

energy comes from the heat developed in the leads, the so-called I^2R losses, (I = current, and R = lead resistance) and the heat conducted away from the hotter parts of the radiator by the leads and whatever supports are necessary to properly carry the radiator which is the filament in the case of the incandescent lamp. The resistance of the leads can be made extremely low and thus, the I^2R losses would be very low, but this would increase the heat conducted away and also there is generally a limit to the size that can be used for such leads. For the 115-volt incandescent lamp the lead loss amounts to from about 0.1 to 0.5% of the energy.

If it is necessary to mount the radiator in a glass bulb, as is the case for an incandescent lamp, another source of heat loss is introduced; i.e., the part of the energy radiated by the filament that is absorbed by the bulb which amounts to from 3 to 5% of the input depending upon the kind of glass used and the character of the radiation from the filament.

There is an added source of loss in many of the present-day incandescent lamps due to the use of a gas inside of the bulb to help reduce the rate of evaporation from the surface of the filament and thus to allow it to be operated at a higher temperature, which means a higher efficiency.

To reduce the size of the light source in all types of lamps and to help overcome the gas losses in gas-filled lamps, the filaments are now coiled into a helix. This introduces another loss in efficiency which will be discussed later.

Another source of loss is the radiation that is intercepted and absorbed by the base of the lamp. The base is of such a size for the average incandescent lamp that it intercepts something of the order of 1% of the output radiation, but it probably does not absorb all of this so 0.5% should be a fair figure.

An important problem of the lamp engineer is to keep these losses as low as possible. These losses in Edison's early vacuum carbon incandescent lamp amounted to about 7.5% of the input. These were made up of about 0.3% due to the resistance of the leads, 0.5% due to base absorption, about 2% due to the conduction of the leads and supports and about 5% due to the heat

absorbed by the bulb. When the vacuum tungsten filament incandescent lamp was introduced, about 30 years ago, these losses were increased due to the necessity of introducing more supports to carry the filament. The carbon filament required but a single support in addition to the two leads because the carbon filament as used was strong enough to maintain its shape even at the higher temperature at which it was operated. However, due to the low resistance of the tungsten filament and hence, its great length (about 50 cm.), it was at first found necessary to use 13 supports (later reduced to 11) in addition to the two leads. It was found that each lead or support in a tungsten filament lamp conducted away about 0.5% of the input energy of the lamp. Thus, the 13 supports and two leads would cause a loss of about 7%. This meant a total loss for the first vacuum tungsten lamps of about 12%.

As a radiator the tungsten filament (in a vacuum, with 11 supports) is very efficient, since about 92% of the energy input is radiated by the filament but not beyond the bulb. Another point in favor of this lamp is that it requires no extra apparatus for its operation. Due to later developments as to the form and shape of the filament, the number of supports has been reduced until the present-day 115-volt lamp has, in general, three supports and in some of them only one. A reduction from 11 to 3 supports reduces these end losses to about 2%.

LIFE OF AN INCANDESCENT LAMP

The life of a tungsten filament depends upon the evaporation from its surface. Tungsten has a very low rate of evaporation even at high temperatures of operation. If it were possible to make a perfect tungsten wire, that is, one of uniform cross section and even crystallization, a lamp could be made from such a wire that would never burn out on constant voltage. If the material were evaporated from the surface of such a uniform filament, the temperature would be gradually reduced until finally it would give no light. However, it is not possible to make such a wire. There are always spots on the wire that, due to one cause or another, operate at a slightly higher temperature than the main

part of the filament. Thus, as the filament vaporizes, these become correspondingly hotter until finally failure develops at that point. Such spots may be caused by impurities, by the state of crystallization or by some injury to the wire in the process of coiling. This is one source of short life that has been very greatly reduced during the past few years and the elimination of the more serious of such spots has been responsible for some of the small increases in efficiency that have been obtained.

There is always a race on between the ability to find such spots and the work to eliminate them. One evidence of this is that the apparatus used to study these spots about ten years ago has but little value today since the spots that could be detected by the old apparatus have all been eliminated and the engineer now is looking for smaller spots. The general feeling is that as soon as a spot is definitely discovered, means can be found for its elimination.

GAS-FILLED LAMPS

Various means have been devised to reduce either the rate of evaporation or its effect upon life. Thus far, but one method has been found for reducing the rate of evaporation from the surface and that is to surround the filament with an inert gas. Some early attempts were made to use an inert gas in the bulb surrounding the carbon filament, but this was not successful. Later, pure argon was used in an ordinary carbon lamp and, while the use of this gas at approximately atmospheric pressure inside the bulb so reduced the evaporation of the carbon that it could be operated at a much higher temperature, there was no increase in the efficiency because the losses due to conduction and convection by the gas far out-weighed any gain in efficiency due to a higher operating temperature.

Some thirty years ago Langmuir (*1*) made a study of this problem and found that a hot filament in a gas was surrounded by a static sheath of the hot gas. The thickness of the sheath depended upon the temperature of the filament and the kind of gas used. Further experiments showed that the percentage gas loss was much larger for filaments of small diameter than for

filaments of larger diameter. These results led to the idea of coiling the filament into a helix and it was found that the gas sheath covered the entire helix and that the gas loss depended not upon the length and diameter of the filament, but on the external diameter and length of the coil.

When the first attempts were made to coil the filament of tungsten lamps, it was found that if the filaments of the smaller wattage lamps were made into a coil of very large diameter, the coil did not maintain its shape at high temperature so could not be used in a lamp. However, at this early time it was found possible to coil the filament of a 500-watt lamp and fill the lamp bulb with nitrogen to approximately atmospheric pressure and obtain an increase in the efficiency of about 40%, not withstanding that the gas losses were probably about 10 to 15% of the input in this lamp. Later, the engineers working with tungsten wire developed a non-sag wire from which it was found possible to coil the wire for a 50-watt lamp into a helix of such a size that the gas losses were reduced to a value such that a 50-watt gas-filled lamp could be made that was more efficient than the vacuum lamp of this wattage. Later developments made it possible to make a gas-filled 40-watt lamp that was more efficient than the corresponding vacuum lamps, notwithstanding that the gas loss for such a lamp amounted to about 25% of the input even when the filling gas was 86% argon and 14% nitrogen. The filament wire must be of such a character that it can be coiled on a mandrel large enough for the proper size helix and then it must be made to keep its shape at high temperatures to such an extent that none of the turns are shorted out.

The first gas used was nitrogen. It was early recognized that argon or some of the other inert gases would make a better getter than nitrogen for two reasons. In the first place, the heat conduction of these rare gases is much less than the nitrogen so there would be less loss due to conduction and convection and then, according to what has been called the Ludwig-Soret effect, the rate of evaporation of the tungsten from the filament is much less when it is surrounded by a gas having a heavy molecule.

At first it was impossible to obtain enough argon at a price

that would make it practical to use it as a getter in the lamp. A factory manager was heard to remark when they first started filling the large lamps with argon that a certain 1000-watt lamp that he was making contained about 30¢ worth of this rare gas. Later developments on methods of obtaining this argon from the atmosphere have so reduced the cost that the 1000-watt lamp today contains probably less than 1/30 this value of argon. Today there is some agitation for the use of krypton as a getter.

About 0.9% of the atmosphere is made up of argon while krypton is but about one millionth part of the atmosphere. From these figures it can be seen that to obtain a liter of argon (enough to fill ten 40-watt lamps) requires the working over of at least 110 liters of air while to obtain a liter of krypton would require the working over of about 1,000,000 liters of air, in other words, about 10,000 times as much as to obtain one liter of argon. These figures are for 100% of separation, which would be very difficult to obtain—there would always be some losses.

Of course, some of the by-products that could be obtained would help in defraying this expense, as in the case of obtaining argon. The krypton would make a better getter for the same two reasons. Its heat conductivity is somewhat lower than the argon and it has a heavier molecule. For a lamp of 40-watt size the increase in efficiency due to the decrease in the heat convection and conductivity would amount to 10 to 12%, and the gain caused by the decrease in the rate of evaporation of the tungsten, due to the increased weight of the molecule, would be of such a magnitude that it would permit an increase in temperature of the operation of the tungsten filament that would give us an additional gain in efficiency of 10 to 15%, making in all 20 to 25% gain in the efficiency of the lamp. Lamps filled with krypton are being made in Europe, but there they have a somewhat different problem. Most of their voltage is 220–230 rather than 115–120 and thus their 100-watt lamp corresponds in efficiency to our 50-watt lamp, since a 100-watt lamp on 230 volts would have the same size filament as the 50-watt lamp on 115 volts. According to calculations, even for very favorable conditions, the cost of extracting krypton from the atmosphere would be such that it

does not seem possible, in this country, to make lamps for ordinary lighting purposes that are filled with krypton, unless the price of the lamp is greatly increased, and the increase in price would probably have to be more than could be justified by the 25% gain in efficiency to be expected for the 40-watt lamp.

EFFICIENCY OF LIGHT PRODUCTION

The incandescent lamp as a transformer of electrical energy into radiant energy has a very marked advantage over the newer types of lamps. Since the incandescent lamp requires no outside equipment except a service line and a socket, there are no external losses in controlling apparatus, and also this lamp has no effect on the power factor of the line. One should not consider too seriously losses in a radiator if the radiator is to be used as a lamp source. Sometimes the losses are large, but the question to be considered is whether the lamp, after considering the losses, is more efficient than the lamp it is to replace. A good example is the gas loss in a 40-watt gas-filled lamp. Although when this lamp is filled with 86% argon, the loss amounts to 25% of the input, such a lamp is more efficient than the corresponding vacuum lamp and it is sold at exactly the same price. This same thing is true with the losses that are found in some of the newer lamps; although they may amount to many percent of the input the question to be considered is, "Does the lamp, after considering these losses, produce light at a satisfactory efficiency?"

LIFE AND FILAMENT DIAMETER

The life of a tungsten-filament incandescent lamp when operated at a constant temperature increases with the filament diameter, which means that for the same life the larger wattage lamps can be operated at a higher temperature and thus at an added gain in efficiency. This is because the rate of evaporation depends upon the area while the resistance which determines the wattage depends upon the volume per unit length which increases faster than the surface. The figures given in Table 1 were calculated from the data given in Table 2 and show the variation of life of three different wattage incandescent lamps if each one

TABLE 1

Lives of three lamps at various temperatures

	LAMP		
	40-watt	100-watt	500-watt
Lumens per watt	11.7	16.1	20.3
Temperature	2,715	2,860	2,945
Life of lamp at temperature in column 1			
2715°K	1,000	4,000	14,350
2860	200	750	2,750
2945	60	250	1,000

TABLE 2

Variations of lumens, lumens per watt, watts, temperature, and life, with voltage of 40-, 100- and 500-watt, 115-volt gas-filled tungsten lamps

LAMP	VOLTS				
	105	110	115	120	125
40-watt					
Current (amp.)	0.333	0.341	0.348	0.356	0.364
Temperature (°K)	2,643	2,682	2,729	2,775	2,821
Lumens per watt	9.64	10.75	11.90	13.08	14.32
Per cent watts	87.5	93.8	100	106.6	113.7
Per cent lumens	70.8	84.9	100	117.4	136.4
Per cent life	432	201	100	52	28
100-watt					
Current (amp.)	0.830	0.850	0.870	0.890	0.910
Temperature (°K)	2,768	2,814	2,860	2,905	2,949
Lumens per watt	13.35	14.72	16.10	17.54	18.95
Per cent watts	87.1	93.5	100	106.8	113.7
Per cent lumens	72.5	85.6	100	115.8	133.4
Per cent life	373	189	100	55	31
500-watt					
Current (amp.)	4.135	4.245	4.345	4.450	4.550
Temperature (°K)	2,852	2,905	2,955	3,005	3,053
Lumens per watt	17.33	18.81	20.30	21.78	23.29
Per cent watts	86.9	93.4	100	106.8	113.8
Per cent lumens	74.1	86.5	100	114.6	130
Per cent life	328	178	100	58	35

is operated at the temperature corresponding to the normal operating temperature of the other two. These figures show that if the 500-watt lamp were operated at the temperature of the 40-

watt lamp it would have a very long life, and the 40-watt lamp would not last very long at the temperature at which the 500-watt lamp has a life of 1000 hours. Another method of illustrating this is by the results shown in Fig. 1 which were calculated to show the efficiency of the 40-watt and 100-watt lamp when the lamp is designed to operate at the various voltages. These curves show that the efficiency increases as the voltage is decreased which means, of course, that the efficiency increases for the larger wire diameter, since a low voltage lamp of the same wattage must take more current and hence must have a filament of larger diam-

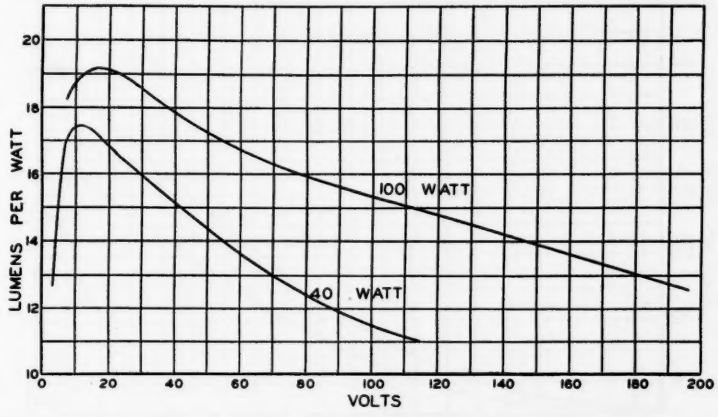

FIG. 1. LUMENS PER WATT FOR DIFFERENT VOLTAGE INCANDESCENT LAMPS (40-WATT AND 100-WATT LAMPS)

eter. This variation in efficiency, which shows a maximum at about 15 to 20 volts, is for the lamps alone. There is some question whether it would be cheaper to use these low-voltage lamps, although they are higher in efficiency, because the assumption is made that the power can be obtained as cheaply at these lower voltages as it is at voltages near 115. This is probably not true since the distribution costs would go up for the higher currents. This is one consideration that led Edison to develop the carbon lamp which he brought out about sixty years ago, that is, a lamp to operate on a line voltage at about 100 to 120 volts and at such an efficiency as to give a satisfactory light out-

put. This finally resulted in the 50-watt carbon lamp which gave about 16 c. in a horizontal direction.

COILED FILAMENT AND EFFICIENCY

A coil filament of tungsten is a less efficient producer of light than a straight tungsten filament, due to the fact that a portion of the radiation from between the coils approximates that of a

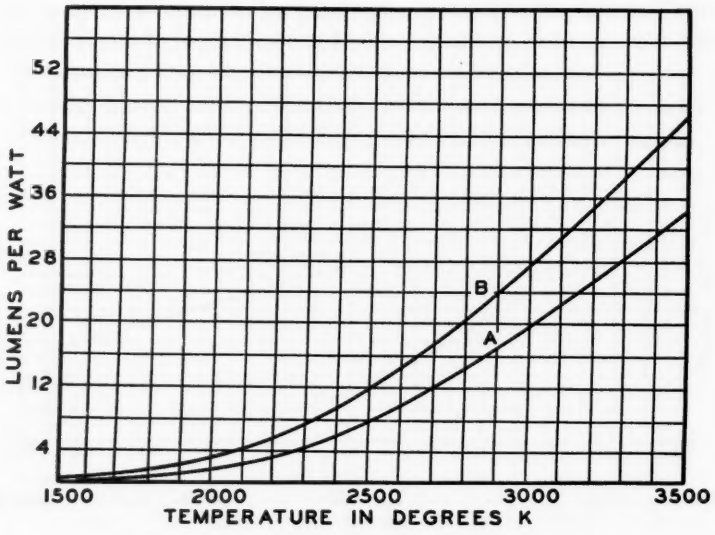

FIG. 2. LUMINOUS EFFICIENCY OF A BLACKBODY
Curve A, tungsten; Curve B, as a function of temperature

blackbody at the temperature of the filament and a blackbody is a less efficient producer of light than a tungsten filament.

The curves of Fig. 2 show the difference in efficiency between tungsten and a blackbody when they are at the same temperature. It is somewhat difficult to estimate just how much of the radiation from coiled filaments approximates that of a blackbody and how much is tungsten radiation. To make a test, measurements were made on a 6.6 amp. street series lamp that has a single coil

mounted vertically with a pitch of 163%, external diameter, 0.8 mm., and the wire diameter of 0.24 mm. The true temperature of the center turns of the filament was measured and the color temperature calculated from the true temperature, and a value of 2780°K. found. The color temperatue of the same turns was then measured directly by screening the end turns. This measurement of course included the radiation from between the coils, a value of 2766°K. was found as a result of tests on two lamps. The blackbody radiation from between the coils corresponds in temperature to that of the filament to within better than a degree or so and thus the value for the coil as a whole is some average between the tungsten and the blackbody radiation. If it be assumed, and this assumption was arrived at from a consideration of the size and shape of this coil, that 20% of the radiation corresponds to blackbody radiation, the average temperature would seem to be about right. Another method of testing this is as follows.

Tungsten at the maximum temperature of the 40-watt incandescent lamp would have an efficiency of about 18.1 lumens per watt while this lamp has an efficiency of 11.7 lumens per watt, a difference of 35.3%. This difference is to be charged up to the various losses in efficiency. In this case, the gas loss amounts to 24.5%, base loss 0.6%, lead loss about 0.2%, the end loss 3.8%, the absorption by the bulb about 1%, making a total of about 30.1%. This leaves about 5.4% to be charged to the poorer radiating character of the coiled filament as compared to a straight filament. Tungsten at the temperature of the 500-watt incandescent lamp would have an efficiency of 25.2 lumens per watt while the lamp as operated has an efficiency of 20.3 lumens per watt. This is a difference of 19.4%, again to be charged to the various losses. For this lamp the gas loss amounts to 9.2%, end loss 4.2%, base loss about 0.5%, leads about 0.5%, and the absorption of the bulb 1%, a total of about 15.4%, leaving 4% to be charged to the poor radiating characteristics of the coil. Again, if it be assumed that about 20% of the radiation has the character of a blackbody and 80% of tungsten, a good check is obtained.

LAMP LOSSES AND LAMP EFFICIENCY

The various losses are not all equally effective in reducing the efficiency of the lamp. The 3 to 5% loss due to the absorption of the bulb does not reduce the efficiency by a corresponding amount because most of this absorbed energy is of very long wavelength. The absorption of the bulb for light probably does not account for more than 1% of the light output of the lamp, which would reduce the efficiency by about 1%.

The amount of energy conducted away by the leads reduces the efficiency more than the amount of energy lost, because not only is this energy lost, but a part of the filament (due to this cooling) operates at a lower temperature, which results in a larger loss in efficiency. The gas loss, the lead loss, and the loss by absorption of the base probably affect the efficiency directly.

There are certain advantages to be gained in coiling the filament even for a vacuum lamp. First, the filament is concentrated into a smaller space, which permits the use of a smaller bulb. Again, this coiled filament requires a smaller number of supports than the straight filament in order to keep it in shape. The straight filament requires about 11 supports while the new coiled filament requires only three and this reduction of 8 supports reduces the loss by about 4%. Each turn of the coil has its temperature raised both by radiation from the other coils and by screening of its own radiation so that the current for a definite wattage would heat this wire to a much higher temperature than when the wire was straight. To overcome this, a larger wire diameter is used which makes for a longer life. The rate of evaporation from a coil is much less than from a straight wire because some of the tungsten particles that leave certain parts of the coils strike a part of the same turn or other turns and are thus trapped. This again permits operating at a higher temperature for the same life, which results in a higher efficiency. These advantages apply to both the vacuum and the gas-filled lamp.

LIFE AND FILAMENT TEMPERATURE

The life of an incandescent lamp depends upon the temperature of the filament, because the temperature in relation to other

factors such as the kind of gas and the gas pressure inside of the bulb, the way the filament is coiled, the method of mounting the coils, and probably some other conditions, determine the rate of evaporation of the tungsten.

The lamp engineer generally relates the other characteristics to the applied voltage or the efficiency in lumens per watt. The temperature of the filament of the 115-120 volt tungsten lamp has been found to be related to the voltage by the following equation

$$V = KT^{2.7}$$

for not too large changes from normal operating conditions, K being a constant that depends upon the lamp wattage and some other factors.

CHARACTERISTIC EQUATION OF INCANDESCENT LAMP

The engineers at the National Bureau of Standards (*2*) have given equations showing the relation between various lamp characteristics. These equations take the following form:

$$\text{Log}\,\frac{L}{L_0} = A \log \frac{V}{V_0} + B \log^2 \frac{V}{V_0}$$

and like equations for other variables. If the proper coefficients are used in such equations, they give very accurate results over a wide range of voltages. Lamp engineers use similar equations but neglect the second term on the right and thus express this equation in the following form:

$$L = K_1 V^{-d} = K_2 E^{-b}$$

$$lu = K_3 V^k$$

where L is the life in hours; lu, lumens; K, a constant; d, b, and k being so-called constant exponents. The values of these various exponents have been determined from the accumulated life data by the test engineers and have been given in an earlier publication (3). If the proper value of the exponent is used, these equations give quite accurate results.

MINIMUM COST OF LIGHT

The life of a tungsten lamp for the minimum cost of light may be determined as follows:

$$\text{Cost of light per lamp} = A + B + CLW$$

where A is the cost of the lamp; B, any charge necessary for servicing the lamp; C, the cost of power per kilowatt hour; L, the life, and W, the wattage of the lamp (in kilowatts). If both sides of this equation be divided by the total lumen-hour output of the lamp during life, the cost per lumen-hour (neglecting the service charge) will be as follows:

$$\text{Cost per lumen-hour} = \frac{A}{LWE} + \frac{C}{E}$$

Now if all of these variables be expressed as an exponential relation of the life and the conditions set up for the minimum cost of light, the values of the life for this minimum cost of light can be determined as a function of the exponents, the cost of the lamp and the cost of power. Thus, the life for minimum cost of light depends upon the cost of power and the cost of the lamp. Whether an additional cost must be inserted for servicing the lamp depends upon the circumstances; in general it can be neglected, but if it is inserted it goes in as an additional cost of the lamp. The final result obtained for the life will depend upon the factors kept constant. If the filament dimensions be kept constant, one result will be obtained. If the filament dimensions be changed so as to keep the wattage constant, another result will be obtained. Such a calculation shows that for a constant wattage lamp operated at constant voltage light is produced at minimum cost for a value of the life given as follows:

$$(b' - 1)A = CWL$$

where the constant b' has a value of about 7.5 for the 40-watt lamp, 7.8 for the 100-watt lamp and about 7.8 for the 500-watt lamp. However, whatever condition is set up a value can be found for the life which will result in a minimum cost of light to the consumer.

Table 2 shows some values for the various characteristics of three incandescent lamps, that are used for illumination purposes, as the voltage is varied.

The cost of light has been calculated for these same lamps for the same conditions of operation and the results shown in Table 3.

The costs of power used in these calculations are about what the average user of the various sized lamps pays. The list price of the lamps have been used in these calculations. If a large user of lamps were considered, some adjustment would have to be made because many large users of incandescent lamps (such as, for instance, the United States government) purchase their lamps at a discount. Also, a large user of power might be able to purchase his power at a lower cost than that given in the table.

TABLE 3

Unit cost of light, per million lumen-hours for 115-volt lamps operated at

LAMP	LAMP COST	POWER COST	105V	110V	115V	120V	125V
40W	$.15	$0.03	$3.46	$3.19	$3.04	$3.02	$3.15
100W	.15	0.025	2.05	1.90	1.81	1.75	1.75
500W	1.20	0.02	1.39	1.32	1.28	1.27	1.30

If these factors are considered, different values will be obtained for actual cost of light, but since the optimum life depends on the *ratio* of costs of lamp and power, there is partial compensation.

Using the best-known values of the constant (*3*) in the above equations, the voltage and the corresponding life for minimum cost of light for these particular lamps has been calculated and the results are shown in Table 4. It is to be noted that for minimum cost of light to the consumer these lamps should each be operated at over-voltage and hence at a shorter life than normal. Another calculation has been made, this time to determine the lives of these same lamps for minimum cost of light assuming that the wattage and voltage were kept constant. These results, including the cost of million lumen hours light under each condition, are shown in Table 5.

The data in these two tables give another illustration of the

fact that higher-wattage lamps are more efficient. The lamps whose data are given in Table 4 are 5% to 10% higher in wattage than those in Table 5. This slight difference in wattage causes the slight difference in efficiency and minimum cost of light.

Mazda incandescent lamps are designed so that their average life is longer than the life for minimum cost of light. This is done to compensate for any "nuisance value" assigned by users to more frequent changes of lamps.

TABLE 4

Operating conditions for three 115-volt incandescent lamps for minimum cost of light

LAMP	LAMP COST	ENERGY COST PER KWH	OPERATING VOLTAGE	OPERATING WATTS	LIFE IN HRS.	LPW	COST OF 1 MILLION LUMEN HRS.
40W	$.15	3¢	118.6	41.9	624	12.75	$3.01
100W	.15	2½¢	122.6	110.3	305	18.22	1.74
500W	1.20	2¢	118.6	524.4	675	21.35	1.26

TABLE 5

Operating conditions for three 115-volt constant wattage lamps for minimum cost of light

LAMP	LAMP COST	ENERGY COST PER KWH	OPERATING VOLTAGE	OPERATING WATTS	LIFE IN HRS.	LPW	COST OF 1 MILLION LUMEN HRS.
40W	$.15	3¢	115	40	850	12.16	$3.04
100W	.15	2½¢	115	100	418	17.35	1.78
500W	1.20	2¢	115	500	836	20.77	1.27

Taking account of the quanitity discounts (*4*) given to large users of lamps, there is no economic justification for operating lamps under voltage unless power can be bought for less than one cent per KWH.

Lamps for general lighting purposes are so designed as to have lives on the average of 1000 hours, 750 hours, and 500 hours, depending upon the lamp and the service for which the lamp is intended.

FREQUENCY OF REPLACEMENT OF INCANDESCENT LAMPS

If lamps could be constructed identically alike, and burned under identical conditions, they might be expected to have a

quite definite life, and to fail "in unison" at the end of, say, 1000 or 750 hours. Such a degree of uniformity has not been attained, and a consideration of the exponent in the equation relating life and voltage shows that it is not likely to be attained. Since that exponent is over 10, keeping the voltage and the filament lengths uniform to within 0.1% would still leave differences in life of more than one percent, that is more than ten hours of actual burning time, even if no other variables than voltage and filament length were operative.

The difficulties attending control of filament length and voltage to 0.1% can be seen from an analysis of the controlling factors: the length of a 100-watt lamp filament is of the order of 50 cm. (20 in.). One-tenth percent of this is 0.5 mm. (1/50 in.). The filament is coiled into a helix one turn of which corresponds to nearly 1 mm., that is 0.2% of the length of the filament, and the filament must be clamped to the leads at both ends. Unless the clamping is very carefully done, errors as great as a whole turn may be introduced. Add to this that slight stretching of the coil affects the rating of the lamp even with the actual length of filament unchanged.

The resistance of a 30-foot branch circuit of 12-gage wire is approximately 0.1 ohm, so that the line drop produced by a single 100-watt lamp is nearly 0.1 volt (in 115 volts). If the circuit loading, due to appliances, were 1000 watts (well within the capacity of a 15-ampere circuit fuse) the line drop would be 0.8 volt, more than two-thirds of a percent change in voltage. Field surveys show that a one-volt line drop in residential circuits[1] is a common occurrence, and since the length of wire outside the house usually exceeds that of the longest circuit, variations in voltage at the service entrance are frequently even greater than one volt. The existence of such voltage variations renders a high degree of uniformity in lamps a matter of little or no practical importance in residential service.

It may even be argued that such a degree of uniformity would be undesirable, even if it could be attained, for many services.

[1] In some other types of service, voltage drops much larger than this are often found.

The housewife would not be pleased to have all the lights in a dining-room chandelier go out just as soup was being served, and many users of electric signs could not be trusted to forestall the complete "black-out" which would theoretically be possible with perfectly uniform lamps.

As matters stand, the lamp engineer is reproached both for the uniformity and for the non-uniformity of his product. If an occasional lamp, designed to last 1000 hours, fails after only

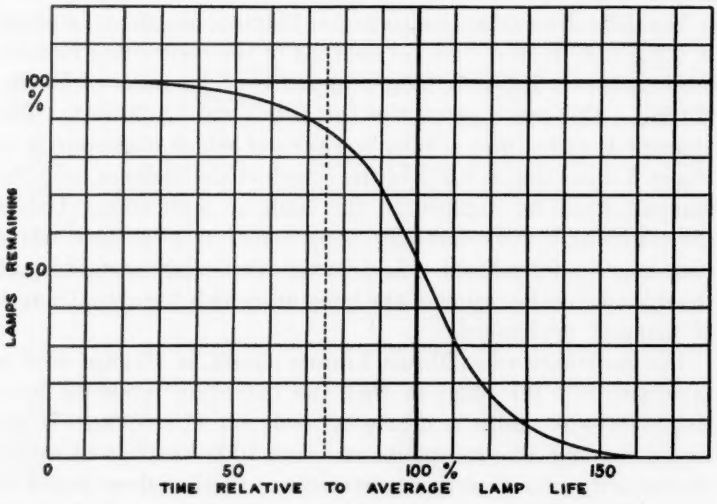

FIG. 3. AVERAGE MORTALITY CURVE FOR TUNGSTEN FILAMENT INCANDESCENT LAMPS

500 hours of useful life, the customer feels that he has a right to complain. If, on the other hand, after a thousand hours of uneventful performance, more than half of the lamps in a particular installation fail within a week, the customer is apt to forget that lamps, like men, are mortal, and the momentary excess of failures is due not to the badness, but to the goodness of the lamps.

Tests of many lamps, of many types, over many years, have given the average life curve shown in Fig. 3 and in Fig. 4, curve *L*. The rate of first replacements, which may be obtained by

measuring the (negative) slope of this curve, is given in Fig. 4 by curve 1. A similar, but lower and broader, curve 2, will give the distribution of second replacements, and so on. The summation of these gives the distribution of total replacements, shown by the uppermost line, *T*, of the figure.

In order that these figures may apply to a lot of any number of lamps of any desired average life, the average life has been taken as a basis, and the total burning time of the installation expressed in percent of the average life of one lamp. Similarly the number

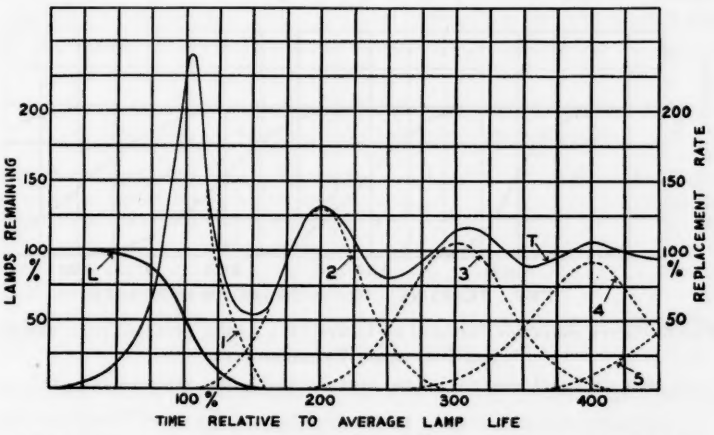

FIG. 4. MORTALITY CURVE (*L*) AND REPLACEMENT CURVES 1, 2, AND 3 FOR TUNGSTEN FILAMENT INCANDESCENT LAMP

of lamps of the original installation, or of any particular replacement, are expressed as a percentage of the total number of sockets. The life curve is inclined downward to the right at 45°, at the times at which the rate of replacement would suffice to replace all the lamps in a time equal to the average life. This is taken as unit rate of replacement (i.e. 100%) in curves 1, 2, 3, etc. The actual rate of replacement (in lamps per hour) corresponding to this unit is given by dividing the total number of lamps by the average life in hours, e.g., one lamp per hour for 1000 lamps of 1000 hours average life.

The division of lamps, at any time after the original installation, between lamps originally installed and the first, second, third, etc. replacements in that particular socket, is shown in Fig. 5. It can be seen that while the original lamps are practically all gone before any considerable number of second replacements have been made, at a later time there is marked overlapping, so that the minima of replacement rate become shallower and shallower, and the peaks correspondingly lower. At the limit the uppermost curve of Fig. 5 would become horizontal, indicating a uniform "unit" rate of replacement of lamps.

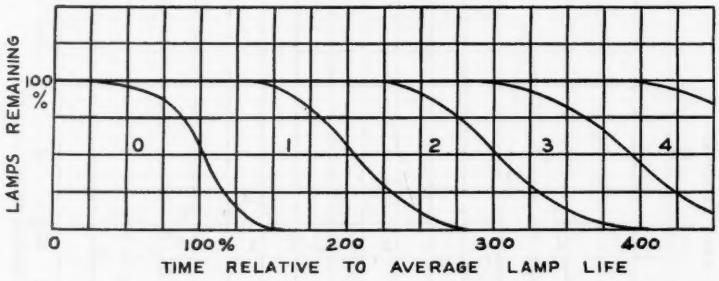

FIG. 5. CURVE SHOWING DIVISION OF LAMPS, IN A LARGE INSTALLATION, AMONG THE DIFFERENT REPLACEMENTS

Area marked 0, original lamps; area marked 1, first replacement, etc.

Such smooth curves will be obtained only for a very large installation. For moderate numbers of lamps, the statistical uncertainty will prevent the curve of replacements as a function of time from settling down to a steady level after a few times the average life of one lamp.

As an illustration, there are approximately 23 million residential users of incandescent lamps in the United States. That rather hypothetical creature, the average American consumer, uses 8 lamps per year. Data are not available as to the precise distribution of lamp demand, nor as to the relation between the number of active lamp sockets and the number of lamps replaced per year.

In default of such data, a calculation has been made by using

Poisson's (*5*) probability summation of the burnouts in an average calendar week of a 365-day year, assuming that the probability of a burnout is the same for each consumer, and independent of the time since the last burnout. The results of this calculation are given in Table 6.

The Poisson formula, like the normal (Gaussian) law of errors, is a limiting case of a binomial distribution, for a number of possible occurrences much greater than the average number of actual occurrences. The Gaussian formula gives the algebraic sum of a large number of error-components which are equally likely to be positive or negative. The Poisson formula gives the number of occurrences of discrete events—ones which either do or do not

TABLE 6

Probability summation of lamp burnouts in one selected week

Number of customers with no burnouts	19,728,605
Number of customers with 1 burnout	3,026,854
Number of customers with 2 burnouts	232,197
Number of customers with 3 burnouts	11,875
Number of customers with 4 burnouts	455
Number of customers with 5 burnouts	14
	23,000,000

happen, which if they once occur will not be undone, and which are no less likely to occur because of a previous occurrence.

As an illustration, getting four aces in a bridge hand is a rather unusual event; getting four aces in each of four consecutive deals would be rare indeed, yet has probably happened many times in the history of bridge whist. Similarly with 23 million customers and a period of 52 weeks, that is, more than one billion customer-weeks, account must be taken of very remote possibilities.

This table states that, subject to the simplifying assumptions made, nearly 20 million out of the 23 million lamp customers in the United States, will have no burnouts in any arbitrarily selected period of 7 days, while 3 million will have one burnout. Less than a quarter million will have 2 burnouts that week; less than 12 thousand, 3; 455, four; and 14 customers will have 5

burnouts in the selected week. On the assumptions made, the total number of customers with 3 or more burnouts in some calendar week in any year will be $52 \times (11875 + 455 + 14)$, or more than 640,000.

There is a further possibility that a succession of burnouts in the latter end of one week may be followed by one or more in the beginning of the next week. Consequently the number of customers with 5 burnouts in a period of 7 consecutive days beginning in a particular day will be somewhat greater than 14. An approximate calculation gave 52, and the departure from uniformity of weeks and customers would almost certainly make the actual number of such coincidences considerably larger than this figure, in spite of the tendency of the improbability of two burnouts in the same week in the same socket to lower the result.

It may be concluded that every year several thousand customers will have 5 burnouts within 7 consecutive days, even though the expected interval between burnouts is more than 6 weeks! It is hard to convince a customer who gets such a "jackpot" of lamp failures that there may be nothing wrong either with the lamps or with the voltage at which they have been operated; and many customers permanently increase the cost of light to themselves by insisting on higher-voltage lamps after such an experience.

In case the disadvantages of burnouts during the period of use are considerable, or the cost of replacing lamps one at a time is much greater than that of making a "clean sweep," group replacement may be used to advantage, as is done in the street lighting of many cities. If all the lamps are changed at 75 percent of the expected life, as indicated by the dotted vertical line in Fig. 3 most of the lamp failures will be forestalled, at a sacrifice of unused burning hours which is more than balanced by the reduction in cost of replacement. Furthermore, in many locations lamps need cleaning after, say, 1000 hours of burning time, and will give little light if left undisturbed, however much beyond the normal expectation they may survive. With some types of lamp it is possible to tell by inspection whether it is worth while to use the lamps replaced in more accessible and less critical sockets.

GROUP REPLACEMENT

Since uniformity is the essence of group replacement, there are two precautions, often overlooked, which tend to improve the performance of multiple-burning lamps intended to be replaced as a group. One is such wiring design as will equalize as completely as practicable the resistance drop in the various circuits, Fig. 6. The other is clean contact surfaces in the sockets to reduce contact resistance.

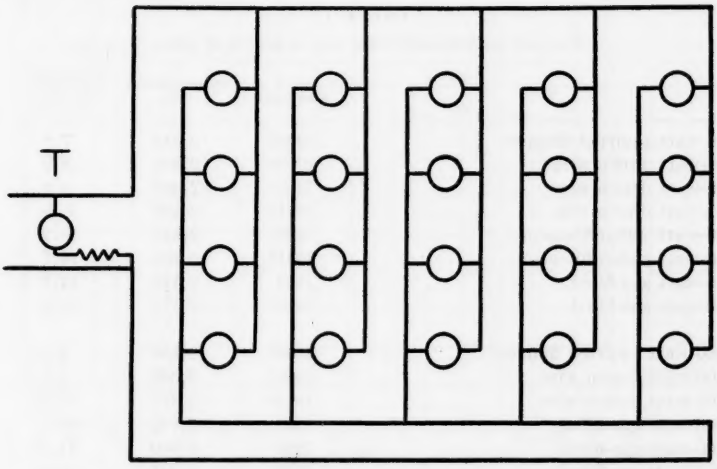

FIG. 6. WIRING DIAGRAM FOR ONE METHOD OF EQUALIZING VOLTAGE DROP ON LAMPS

Since it is often inconvenient to keep a record of burning hours, the line drop can be used to cause a "tell-tale" lamp,—like those in the installation or at least designed for the same voltage and life, to burn out at the time replacement should be made. If the line drop gives too great a disparity in life, a small series resistance may be placed in series with the "tell-tale."

IMPROVEMENT IN INCANDESCENT LAMPS

There has been a very great amount of time spent on the problem of methods of improving the tungsten lamp in the labora-

tories of the General Electric Company since the original Just & Hanemann patents were purchased by the company. This has covered the period from 1907 up to the present time. The question is, "What has been the result of this work?" Some of the more outstanding achievements may be cited: ductile tungsten wire by Coolidge, gas-filled lamps by Langmuir, non-sag wire by Pacz, tipless exhaust by Mitchell and White, inside frost by Pipkin, to mention only a few. One of the direct results

TABLE 7

Increase in lamp efficiency over a period of years

LAMP	DATE MEASURED	TEMPERATURE (°K)	EFFICIENCY IN LUMENS PER WATT
40-watt squirted filament	1908†	2,310	7.8
40-watt drawn wire	1909†	2,320	8.9
40-watt drawn wire	1915†	2,400	9.6
40-watt drawn wire	1921†	2,500	10.0
40-watt coiled filament	1926†	2,545	10.2
40-watt coiled filament	1931†	2,565	10.8
40-watt gas-filled	1936	2,710	11.1
40-watt gas-filled	1938	2,715	11.9
100-watt squirted filament	1908†	2,355	8.8
100-watt drawn wire	1909†	2,360	9.3
100-watt drawn wire	1915†	2,475	10.3
100-watt gas-filled	1921	2,740	12.6
100-watt gas-filled	1932	2,800	14.3
100-watt gas-filled	1936	2,845	14.9
100-watt gas-filled*	1936	2,855	15.5
100-watt gas-filled*	1938	2,860	16.1

* 750 hours life.

† Vacuum lamps.

of these achievements is shown in Table 7. In this table are shown some measurements that have been made on two lamps, that is, the 40-watt, 115-volt tungsten lamp and the 100-watt, 115-volt lamp during the past thirty-two years. These data show that the efficiency of the 40-watt lamp has been increased by more than 50% in the past thirty-two years and that the 100-watt lamp has been increased by more than 70%. It also shows that these improvements have been the result of a number of small improvements during the past thirty years.

The improvement in efficiency is not the only result of the laboratory work. Due to other lines of work that have to do with the method of manufacturing tungsten lamps, methods of manufacture have been simplified and costs reduced so that it has been found possible to reduce the price of the lamp markedly. In 1907–8 the list price of the 40-watt lamp was $1.50 and that of the 100-watt lamp, $2.00. At the present time each of these

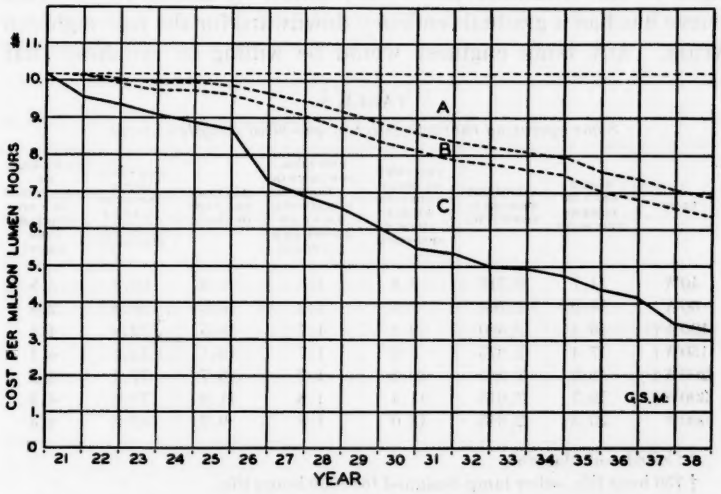

FIG. 7. REDUCTION IN UNIT COST OF LIGHT FOR 60-WATT, 115-VOLT MAZDA LAMP IN RESIDENTIAL SERVICE, SHOWING PART OF REDUCTION DUE TO DECREASE IN ENERGY COST *A*; DUE TO DECREASE IN PRICE OF LAMP *B*; AND TO INCREASE IN LAMP EFFICIENCY *C*

lamps lists at 15¢. Even to a lamp engineer the improvements shown in Table 7 and this reduction in price seem to be a very great achievement. Applying these reductions to the light bills of the 23 million customers mentioned above represents an enormous saving.

Another method has been used to show the reduction in the cost of light to the customer. This is shown by the curve in Fig. 7 which shows, for the 60-watt, 115-volt incandescent lamp, the cost of a million lumen-hours of light, year by year, for the

past seventeen years. This reduction in light cost has been divided into three parts, the first the reduction in cost due to the reduction in the price of the power, the second the reduction in cost due to the change in the price of the lamp, the third the reduction in cost due to the increased efficiency of the lamp. This curve only extends back for about eighteen years and it shows that during this time the cost of a million lumen-hours of light to the consumer has been reduced by about 70%. This curve has had a gradual tendency downward for the past eighteen years. Any lamp engineer would be willing to prophesy that

TABLE 8

Some operating characteristics of gas-filled tungsten lamps

LAMP	EFFICIENCY IN LUMENS PER WATT	FILAMENT TEMPERATURE (°K)	PER CENT OF INPUT RADIATED WITHIN VISIBLE SPECTRUM	END LOSS, PER CENT OF INPUT CONDUCTED AWAY BY LEADS AND SUPPORTS	GAS LOSS, PER CENT OF INPUT	PER CENT INPUT RADIATED BEYOND BULB BY FILAMENT	LOWERING OF EFFICIENCY DUE TO END LOSS (PER CENT)
40W	11.7	2,715	6.8	1.6	24.5	66.8	3.8
60W*	13.9	2,760	7.5	1.2	13.5	80.8	2.8
100W†	16.1	2,860	9.4	1.7	18.5	72.8	4.1
150W†	17.4	2,875	9.6	1.7	16.1	75.1	4.1
200W†	18.2	2,885	10.2	1.7	13.7	77.4	4.2
300W†	19.7	2,915	11.1	1.8	11.6	79.8	4.3
500W	20.3	2,945	12.0	1.8	9.2	82.3	4.3

* Coiled coil filament.

† 750 hour life, other lamp designed for 1000 hours life.

this reduction will continue and that the next period of years will show a further reduction in the cost of light to the consumer.

The curves in Fig. 7 show, in another manner, the comparative effect of lamp cost and lamp efficiency on the cost of light. At the beginning of the period covered by these curves, i.e., 1921, the 60-watt, 115-volt Mazda lamp was listed at 45¢ and had an efficiency of about 9.6 lumens per watt. Now this lamp is listed at 15¢ and has an efficiency of about 13.9 lumens per watt, which is about 67% decrease in lamp price and about 39% increase in lamp efficiency. The saving due to the reduction in the cost of electric power, which was taken at about 7.5¢ per kilowatt hour in 1921 and about 4.1¢ per kilowatt hour in 1938, is about equal

to the saving due to the increase in efficiency while the saving due to the reduction in the cost of the lamp only amounts to about one-sixth of either of these.

Table 8 shows some of the operating characteristics of a number of Mazda lamps that are used for general lighting purposes.

We have had a considerable amount of help from G. S. Merrill, one of the Nela Park Engineering Department lighting engineers, in the preparation of this paper, particularly in the section dealing with light cost and with the statistical study of lamp failures. We appreciate this assistance.

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TAXONOMY OF CHESTER OSTRACODES

CAREY CRONEIS

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The name *Idiomorpha* was proposed in print by Croneis and Gale (1) in this JOURNAL on January 14, 1939, for a new genus of the ostracode family *Glyptopleuridae* from the Golconda (late Mississippian) sediments of southern Illinois. Dr. Paul H. Oehser, of the United State National Museum, has kindly called my attention to the fact that this action apparently has resulted in a new case of homonymy.

Idiomorpha was suggested in 1869 by Förster (2) for a genus of the family of the Cynipidae of the Hymenoptera. Förster reviewed the literature of the Cynipidae and promised a monograph on that family which apparently was never forthcoming. Nevertheless in his preliminary paper he gave synoptic tables for seven subfamilies and characters for 63 new genera of the gall wasps. One of the latter was designated *Idiomorpha*. Accordingly *Idiomorphina* Croneis and Gale is here substituted as the new generic name for those ostracodes originally described under *Idiomorpha*.

Since the publication in this JOURNAL of papers by Croneis and Gale (1), Croneis and Thurman (3), and Croneis and Funkhouser (4) on some of the Chester ostracodes of Illinois, a number of other errata in these articles have come to my attention either through subsequent work or through the kindness of some of my fellow workers, especially Dr. H. N. Coryell of Columbia University. The most important of these irregularities involve several other cases of homonymy, as follows:

Jonesina ? dubia Croneis and Gale (1, p. 267) is preoccupied by Bradfield (1935) in Amer. Paleo., Vol. 22, No. 73, pp. 19, 43. Therefore *Jonesina ? skinneri* Croneis and Gale is here suggested as the new name for this species.

Bairdia ? deloi Croneis and Gale (1, p. 288) is preoccupied

by Kellett (1934) in Jour. Paleo., Vol. 8, No. 2, pp. 125–126. Accordingly *Bairdia ? osorioi* Croneis and Gale is the new name here substituted for this Golconda species.

Amphissites rothi Croneis and Funkhouser (4, p. 346) is preoccupied by Bradfield (1935) in Amer. Paleo., Vol. 22, No. 73, p. 57. *Amphissites bradfieldi* Croneis and Funkhouser is here proposed as a new name for this Clore species.

In addition to these clear cut cases of homonymy, *Sansabella laevis* Croneis and Thurman (3, p. 302) *may* be preoccupied by *Sansabella laevis* (Warthin 1930) Johnson (1936) Neb. Geol. Surv. Paper No. 11, p. 11. Therefore *Sansabella johnsoni* Croneis and Thurman is here suggested as a new name for this Kinkaid ostracode. There are also a number of typographical errors which should be corrected. *Amphissites "fossulus"* (3, p. 313) should be *A. fossilis; Carboprimitia rotunda* var. *"depressa"* (4, p. 338) should be changed to *C. rotunda* var. *tumida;* "Chappers" should read Chappars throughout, and "lesat" (3, p. 307) should, of course, be least.

Following Bassler and Kellett's Index (5, p. 39), we used *Bairdiidae* Lienenklaus (1, p. 286) (3, p. 325) (4, p. 356). Apparently this is an error. The family should be credited to Sars (6, p. 288), who used the term in 1887, eight years before it was employed by Lienenklaus (7, p. 132). We also ascribed the family *Beyrichiidae* to Jones (1, p. 264), whereas, since that writer used *"Beyrichiae,"* it should have been credited to Ulrich (8, pp. 632, 647). We also consistently, and some feel impolitely, used the initials U. and B., although I cannot believe that anyone failed to recognize, in this designation, Ulrich and Bassler.

The foregoing types of errata are particularly annoying, not only because they can be almost completely if not entirely avoided, but especially since we tried hard, but unsuccessfully, to eliminate them. But there are other far more serious errors which are not at once apparent in these and probably in all ostracode papers. Such errata involve problems in orientation, in synonomy, and in the delimitation of taxonomic categories.

The riddle of orientation for Paleozoic ostracodes has already bred scores of articles dedicated to its solution. But there is still

no simple set of rules by which right and left values may be distinguished. Furthermore, if certain rules do seem to work satisfactorily for one genus, their application to other genera is likely to result in serious anomalies. That this is so is amply demonstrated by the fact that almost no major paper on ostracodes is free from at least one case of an ostracode being differently oriented in its written description than in its illustrations. In the description of the Chester ostracodes we have rather consistently considered the thickest portion of the carapace posterior, but we recognize that this criterion, for various reasons, is of no real significance for many genera. Nor do we think of it as sacrosanct even for all of those genera which are at present oriented chiefly on the basis of this criterion. The plain fact is that we do not certainly know how to orient all Paleozoic ostracodes and perhaps we may be forgiven for feeling that no one else does. Since many generic references are dependent solely on orientation, the importance of this problem is by no means minimized by our ignorance of its solution.

Emerson (9) has defined a species as a natural population, genetically distinct, and reproductively isolated. But although such a species concept apparently meets the approval of many geneticists, how does one apply it to paleontology in general, or to Paleozoic ostracodes in particular? Two strains of *Drosophila*, which, under the closest scrutiny, are externally identical, even as to minutae, may be *genetically* distinct. Picture the difficulties of trying to work out the genetic make-up of extinct Paleozoic ostracodes. Yet judged on the gene concept alone, it might appear that all our so commonly condemned paleontologic species splitting has nevertheless certainly resulted in many genetically distinct strains being grouped under the same "species." On the other hand, when one considers the molt problem in ostracode classification, and the complications resulting from sexual differences, the conclusion is inescapable that some of our species are still being based on males versus fertile or non-fertile females, or on growth stages. That is, despite our cognizance of these problems we do know how properly to evaluate them in species delineation. Further, I am of the opinion

that just as some characteristically dextrally coiled gastropods have sinistrally coiled representatives, and just as both modern (10, 11, 12) and Paleozoic pelecypods (13) may display transposed hinge structures, it is also possible that some ostracodes may be marked by heterotaxy, or other reversals. If this be so, many genera of ostracodes based on the familiar, "like genus X, but with reverse orientation," may well be invalid.

The problems of ostracode taxonomy are not lessened by the difficulties attending their illustration. There are many excellent drawings of ostracodes, but unfortunately they do not necessarily look very much like the individuals represented. The problems involved in their photography are equally great, since the best pictures thus far obtained do not necessarily closely resemble the appearance of the specimens when seen under the binocular microscope. As a case in point, while our first three ostracode papers (1, 3, 4) were in press, Coryell and Sohn (14) published a description of several new genera and species from the Reynolds formation of West Virginia. Some of their forms may prove to be conspecific or congeneric with some of our representatives. These possible synonomies, however, probably can only be determined on the basis of comparison of actual specimens; they cannot be definitely established, even where they are strongly suggested, through comparison of Coryell and Sohn's published descriptions and illustrations with our own.

Since I have been at once deeply interested in both the modern genetic concepts as applied to paleontology, and in the value of micropaleontologic groups in stratigraphic analysis, an effort has been made to steer a middle course in the erection of new species of Chester ostracodes. For this reason we have not described as new a large number of specimens in our collection which may well merit such description; but doubtless also we have erected a number of species which later will be reduced to synonomy.

So in conclusion one may well ask: "Who knows what constitutes a valid paleontologic species in any case?" If species of living organisms cannot be differentiated to the satisfaction of all zoologists, how can we expect definitively to delineate

species of extinct organisms on the basis of their inanimate paleontologic fragments? Dobzhansky's solution of this pressing problem as applied to zoology probably has even greater validity for paleontology. He has said (15): "Of late, the futility of attempts to find a universally valid criterion for distinguishing species has come to be fairly generally, if reluctantly, recognized. This diffidence has prompted an affable systematist to propose something like the following definition of species: 'a species is what a competent systematist considers to be a species.' "

I do not propose to go into the problem of what constitutes a "competent systematist."

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NEW OSTRACODES FROM THE RENAULT FORMATION[1]

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INTRODUCTION

The micropaleontologic study of the Illinois Chester sediments (late Mississippian) was undertaken by the senior author a number of years ago at the suggestion of Dr. M. M. Leighton. Although this general investigation is far from completed, recent drilling activity in the Illinois Oil Basin has made it imperative that at least progress reports be published, especially on the studies of fossil ostracodes, since this group may well have utilitarian value in oil field correlation.

This paper on Renault species, and the four other articles on Chester ostracodes published in this JOURNAL indicate some new species and genera to be expected in well cuttings and surface outcrops of the five formations discussed. No attempt is made here to describe the complete ostracode fauna, nor is it practical at this time to give the complete geological ranges for the species which are described. These pages are intended only to provide the bases for future specific comparisons and further research. For this reason some of the references to families and genera, as well as some of the orientations, are to be regarded as provisional.

ACKNOWLEDGMENTS

The Illinois Renault sediments, which yielded the ostracodes herein described, were collected by L. E. Workman and J. E.

[1] Published with the permission of Dr. M. M. Leighton, Chief, Illinois Geological Survey. See Croneis and Gale, this *Journal*, *33*, 251–296 (1938) for more detailed sections concerning Introduction, Acknowledgments, and Laboratory Procedure.

Lamar of the Illinois Geological Survey, or by members of that organization working under their direction. The samples were turned over to the senior author by Dr. M. M. Leighton, chief of the Illinois Geological Survey. To all of these men we owe our thanks. We also are obligated to a number of anonymous graduate students who made preliminary studies of some of the material used, and to W. Schmidt and Michael S. Chappars who kindly rendered valuable photographic assistance.

THE RENAULT FORMATION

The Renault formation occurs in the lower Chester Series (Upper Mississippian) as is shown in the accompanying table of Illinoian Chester formations.

Upper Chester	Kinkaid limestone and shale
	Degonia sandstone
	Clore limestone and shale
	Palestine sandstone
	Menard limestone and shale
	Waltersburg sandstone
	Vienna limestone and shale
	Tar Springs sandstone
Middle Chester	Glen Dean limestone and shale
	Hardinsburg sandstone
	Golconda limestone and shale
	Cypress sandstone
Lower Chester	Paint Creek limestone and shale
	Bethel sandstone
	RENAULT limestone and shale
	Aux Vases sandstone

The Renault formation can be traced, according to Weller, across the entire state of Illinois, from St. Clair County on the west to Hardin County on the southeast. The outcrops are restricted to southern Illinois, Crittenden County, Kentucky and Ste. Genevieve County, Missouri, but by well logs this formation can be traced considerably farther to the east and north beneath younger Chester and Pennsylvanian formations.

The name, Renault, was taken from Renault Township, the southernmost township in Monroe County, Illinois, in which are located the largest outcrops of the formation.

The Renault is composed mainly of limestone with some intermixing of sands and shales which suggest deposition relatively near shore during at least part of Renault time. In Hardin County, Illinois and in Crittenden County, Kentucky, there occur, at the base of the Renault limestone, shaly beds which have been called the Shetlerville formation, the name being derived from Shetlerville, Hardin County, Illinois. The lithologic character of the Shetlerville formation is distinctly different from the underlying Ste. Genevieve limestone. The limestone beds which occur in the Shetlerville shale are crystalline in character, dark gray or blue in color, and cross-bedded in some localities. Gradations occur from shales through shaly limestone to limestone.

The maximum thickness of the Renault formation is approximately 100 feet, but the formation apparently may be wanting at some places in the general area of its outcrop.

The Renault overlaps the basal Chester Aux Vases sandstone and rests disconformably upon the Ste. Genevieve and St. Louis limestones. The sandstone units of the Renault (Weller 1920) are differentiated from the unfossiliferous Aux Vases sandstone by containing a few fossil trunks of a species of *Lepidodendron*. Where the Renault rests upon the Ste. Genevieve limestone the disconformity is marked by a basal conglomerate. Ulrich correlates the "Upper Ohara" limestone with the Upper Ste. Genevieve limestone, whereas, in Weller's classification, it is considered the correlative of the Renault-Shetlerville. Weller (1920) believes that disconformities occur not only between the Renault and Shetlerville formation, but between the Shetlerville formation and Ste. Genevieve limestone. The contact between the Renault and the overlying Bethel sandstone also is sharp, showing a definite disconformity.

Talarocrinus, with thickened plates forming a bilobed base, are characteristic of Lower Chester faunas, especially of the Renault.

RENAULT OSTRACODES

Thirty new species and two new genera of ostracodes are herein described. Comparative studies show that this Renault fauna is more robust and diversified than those from the higher

Chester beds. The Golconda ostracodes are more like the Renault forms than are those from the other Chester formations thus far studied. This is strikingly so for certain glyptopleurids and for the *Bairdia*, *Knoxina*, and *Discoidella* representatives. The ostracodes of the Salem formation, as described by Geis (1932), are, however about as closely related to the Renault species as are those from the Golconda. Menard, Clore and Kinkaid ostracodes appear to be much more advanced; especially is this true of the glyptopleurids. Some *Amphissites*, however, which are present in the Renault are close relatives of forms found as high as Kinkaid.

Morey (1935), in studying the ostracode fauna of the Amsden formation of Wyoming came to the conclusion that the absence of common Chester ostracodes, such as *Amphissites cf. tricollina* and *Glyptopleurina*, indicates that the Amsden formation is older than Chester. This conclusion was also reached by Branson and Greger on the basis of megafossils. Our preliminary studies, however, seem to indicate that the Amsden species are related to those from the Chester beds. *Hollinella*, for instance has not been certainly identified in the Renault, yet it occurs in the higher Chester strata of Illinois as well as in the Amsden. *Glyptopleura multicostata* of the Amsden also resembles Chester representatives of the genus. But final statements concerning Chester correlation must await further studies of the ostracode faunas, which thus far are only partially described.

The primary types illustrated and described in this paper are deposited in Walker Museum, University of Chicago. Secondary types will be placed in the collections of the Illinois Geological Survey.

LABORATORY PROCEDURE

A synopsis of the method of preparing the samples and sorting the sediments, together with a brief statement of the photographic procedure, will be found in Croneis and Gale (1938).

LOCALITY NUMBERS

A list of Chester outcrops from which samples have been collected is on file at the Illinois Geological Survey at Urbana. The

Renault locality numbers cited in this paper may be found in that register.

SYSTEMATIC DESCRIPTIONS

Class CRUSTACEA
Superorder OSTRACODA Latreille
Family Leperditiidae Jones
Genus Paraparchites Ulrich and Bassler
Paraparchites inornatus (McCoy)

Plate I, fig. 13

Cythere inornata McCoy, Syn. Char. Carb. Fossils, Ireland (1844), p. 167, pl. 23, fig. 18.

Paraparchites inornata Harlton, Jour. of Pal., 1, 203, pl. 32, figs. la, b (1927).

Paraparchites inornatus Croneis and Gale, Den. Univ. Bull., Jour. Sci. Lab. 33, 256 (1938).

Dimensions of figured specimen: length, .70 mm.; height, .56 mm.; thickness, .33 mm.

Locality: .0526.41 P29.Q Hypotype, Walker Museum, No. 45151.

Remarks: There are at least two distinct species of this genus in the Renault, namely: *P. inornatus*, a smaller species here figured, and a larger type, *P. robustus*, which is the largest ostracode in the formation. *P. inornatus* has a distinct, straight hinge line on both valves, whereas *P. robustus* shows a rounded dorsal margin on the left valve. Both species are common in the Renault.

Genus Paraparchites Ulrich and Bassler
Paraparchites robustus Croneis and Gutke, n. sp.

Plate I, fig. 11

Carapace large, subovate in outline; hinge line straight, extending about one-half length of shell. Posterior outline much more uniformly rounded; anterior outline broadly rounded anterio-ventrally, becoming more angular anterio-dorsally. Convex venter meets anterior and posterior outlines with subequally rounded curvatures; dorsum of left valve convex, elevated

noticeably above hinge line; dorsal outline of right valve conforms to hinge line. Anterior cardinal angle somewhat higher and more angular than broadly rounded posterior cardinal angle. Surface smooth and uniformly convex.

Dimensions of type specimen: length, 1.73 mm.; height, 1.32 mm.; thickness, .97 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45152.

Remarks: *P. robustus* is similar to *P. inornatus;* but it differs from that species in that the dorsum of its left valve is convex and extends above the hinge line. The Renault species probably represents an ostracode line descendant from *P. subcircularis* Geis of the Salem limestone, despite the fact that it is a smaller, less rounded form.

Family Primitiidae Ulrich and Bassler, emend., Swartz
Genus Perprimitia Croneis and Gale
Perprimitia elegans Croneis and Gutke n. sp.

Plate I, figs. 3–4

Carapace small, subovate in outline. Hinge line straight, extending about three-fourths the length of the carapace. Maximum height posterior to mid-length; greatest thickness posterior. Venter short, nearly straight or only slightly convex, approximately parallel the dorsum. Posterior outline much more broadly rounded than anterior; anterior and posterior ventral slopes subequally rounded. Anterior cardinal angle definite, approximately 125°. Dorso-posterior slope nearly straight and almost vertical, meets dorsum in sharply defined posterior cardinal angle of approximately 90°. Spine located at posterior cardinal angle on right valve only. Swelling in posterio-dorsal quarter rises above the hinge line. Single spines on both right and left valves just below midheight and near posterior margin. Dorsal view bluntly wedge-like in outline. Right valve very slightly larger than left. Fine groove down hinge line, widening posteriorly. Shell smoothly convex.

Dimensions of type specimen: length, .73 mm.; height, .50 mm.; thickness, .47 mm.

Locality: 45.9W 602.74 Holotype, Walker Museum, No. 45153.

Remarks: *P. elegans* resembles *P. bicornis* of the Golconda formation, but differs in that it does not have the sulcus and node near mid-carapace that are so prominent in the Golconda species. *P. elegans* also does not have broad swelling along the venter that is found in *P. bicornis*, but *P. bicornis*, on the other hand, has no swelling in the posterio-dorsal quarter. In addition, *P. elegans* has a less rounded outline than *P. bicornis*.

Perprimitia turrita Croneis and Gutke, n. sp.

Plate I, figs. 24–25

Carapace subrectangular, elongated, small; hinge line straight; cardinal angles obtuse, posterior more abrupt; posterior and anterior outlines broadly rounded; posterior more uniformly rounded than anterior; extremities meet the venter in broad swings; venter slightly convex, slopes gently from anterior to posterior. Right valve larger than left and overlaps it on free margin, overlap greatest along posterior and venter, less on anterior; strong overlap at anterio-dorsal cardinal angle, very slightly so at posterior cardinal angle. Surface marked by three nodes, posterio-dorsal node much the more pointed and rising to a greater height than the two subcircular nodes, one of which is located the posterio-ventral quarter, and the other just anterior to mid-length and slightly above mid-height. Pit located immediately posterior to anterio-dorsal node. Greatest thickness of carapace median; maximum height anterior.

Dimensions of type specimen: length, .63 mm.; height, .39 mm.; thickness, .27 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45154.

Remarks: Since its maximum thickness lies near mid-carapace, it is difficult to orient this species on the basis of thickness as, merely for consistency's sake, we have done for the majority of Renault ostracodes. Orientation is based provisionally on the right valve overlapping the left as is the case in *P. funkhouseri*

of the Kinkaid formation. In *P. turrita*, however, overlap occurs at the cardinal angles, as well as on free margin, a feature not seen in *P. funkhouseri*. The sulcus in *P. funkhouseri* is much more pronounced than in the Renault species.

Family Acronotellidae Swartz
Genus Pterocodella Croneis and Gale
Pterocodella inconsueta Croneis and Gutke, n. sp.

Plate I, figs. 7–9

Carapace small, sub-oblong to sub-ovate in outline; hinge line straight, extending about seven-eighths length of the shell. Maximum height somewhat behind mid-length; greatest thickness posterior; greatest length near mid-height. Posterior outline much more broadly rounded than anterior; anterio-ventral slope long; posterio-ventral slope short and much more bluntly rounded; posterior cardinal angle well defined, approximately 95 degrees. Ventral outline sub-parallel to dorsum in posterior half, but trending upward anteriorly; anterior cardinal angle obtuse. Two large pointed nodes separated by a sub-median depression rise out of each valve. Anterior node sharper than posterior one and pointed forward; posterior node more blunt, rises out of the shell approximately at right angles to hinge line, and is located higher on carapace. Dorsal and ventral views resemble the outline of a flying squirrel. Surface smooth.

Dimensions of type specimen; length, .66 mm.; height, .28 mm.; thickness, .47 mm.

Locality: .0511.51 Holotype, Walker Museum, No. 45155.

Remarks: *P. inconsueta* apparently is related to *P. mirabilis* of the Golconda formation, but it is proportionately longer and thinner, its nodes are sharper and more conspicuous, and its shell is more extended and sharper at the anterior and posterior extremities. The Renault specimens have been referred to *Pterocodella*, however, with some misgivings. If they are correctly placed generically, the generic description will have to be somewhat emended, especially since it may well have been based on the carapace of a female with a number of brood pouches.

Family Kloedenellidae Ulrich and Bassler
Genus Jonesina Ulrich and Bassler
Jonesina holli Croneis and Gutke, n. sp.

Plate I, figs. 14–15

Carapace small, subovate in outline; hinge line straight for about three-fourths length of shell. Left valve largest, overlapping right along free margin, beginning at the cardinal angles; greatest overlap along venter. Grooved hinge area, widest at middorsum. Maximum height posterior; greatest thickness anterior. Anterior cardinal angle obtuse, somewhat more abrupt than posterior cardinal angle which is broadly rounded. Pit located just posterior to mid-carapace and slightly above mid-height of shell. Surface smooth. Vague posterior lobe behind pit.

Dimensions of type specimen: length, .75 mm.; height, .51 mm.; thickness, .44 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45156.

Remarks: *Jonesina holli* is very similar to *J. wrighti* when seen in dorsal view, but its lateral expression shows a less angulated outline, and a less well marked surface.

Jonesina wrighti Croneis and Gutke, n. sp.

Plate I, figs. 22–23

Carapace small to medium sized, subquadrate to subovate in outline. Hinge line straight; cardinal angles obtuse; posterior and anterior outlines broadly rounded; posterior outline tends toward angularity near mid-height; ventral outline of left valve convex; left valve outline less convex and more evenly rounded than left valve; left valve larger than right and completely overlaps it along free margin; overlap along posterior and anterior slight; no overlap along dorsum except at the cardinal angles where left valve overlaps right; overlap greatest at venter. Greatest thickness anterior. Prominent pit located just posterior to mid-carapace; pit forms anterior border of an oval, flat-bottomed depression in posterio-dorsal quarter. Surface smooth.

Dimensions of type specimen: length, .73 mm.; height, .50 mm.; thickness, .40 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45157.

Remarks: *J. wrighti* may be distinguished from all of its relatives on the basis of its peculiar seal-like posterio-dorsal depression.

Genus Knoxina Coryell and Rogatz

Knoxina rogatzi Croneis and Gutke, n. sp.

Plate II, figs. 26–27

Carapace medium sized, sub-semicircular in outline; hinge line straight, running four-fifths length of carapace. Maximum height at mid-length; greatest length near mid-height; thickest near middle of posterior half. Dorsal view resembles an arrowhead pointed bluntly at the haft. Posterior and anterior outlines sub-uniformly rounded, meeting venter in broadly rounded swings, the anterior one being more abrupt; venter broadly rounded. Anterior cardinal angle approximately 120°, posterior angle less obtuse. Surface punctate or pitted, and marked by four ridges. The major ridge originates in the posterio-ventral quarter, slightly below mid-height of shell, and trends gently downward from posterior to anterior, terminating near the anterior margin. Strong "V" shaped ridge, with the point of the "V" pointing posterio-ventrally, located in anterio-dorsal quarter. A small, indistinct ridge lies below the major one in the anterio-ventral quarter, and another occurs as a node-like ridge subparallel the hinge line in the posterio-dorsal quarter. Sulcus slightly above mid-carapace from which area it is extended anterio-ventrally. Small node lies anterior to sulcus, posterior to "V" shaped ridge. Vague ridge on free margins. Valves equal, or sub-equal.

Dimensions of type specimen: length, .75 mm.; height, .48 mm.; thickness, .51 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45158.

Remarks: The surface of the Renault species is more coarsely reticulate than in *K. inflata* of the Golconda formation and the "L" or "V" shaped ridge in dorso-anterior quarter not only has a different configuration but is somewhat differently oriented. Moreover, the sulcus and node in *K. inflata* are more centrally placed than in *K. rogatzi*, and the minor ribs do not appear on the Golconda species. Nevertheless, the two species are closely related.

In Denison University Bulletin, Jour. Sci. Labs. 33, 266 (1938), Croneis and Gale reversed the orientation of *K. inflata* to that used in this description. In Plate VI, fig. 17 of that paper however the specimen is labeled as having the area of greatest thickness posterior—the orientation accepted at present, although, it is admitted, with some uncertainty.

Genus Oliganisus Geis

Oliganisus geisi Croneis and Gutke, n. sp.

Plate II, fig. 10

Carapace small to medium sized, hinge line straight, extending about three-fourths length of specimen; anterior outline with a distinct forward swing, venter straight to slightly convex, sloping upward from front to rear. Dorso-anterior outline straight for the most part, meeting the dorsum abruptly to form obtuse anterior cardinal angle of approximately 125°; meets venter in a relatively narrowly rounded outline; posterior outline broadly rounded to nearly straight, joining dorsum in a rather sharp posterior cardinal angle of approximately 95°; posterio-ventral slope broadly rounded. Maximum height midway between mid-length and anterior extremity; greatest thickness posterior. Valves unequal, right overlapping left very slightly on free margins. Sulcus anterior to mid-length, opening upward to hinge line. Anterio-dorsal node separates subcentrally located sulcus from a less prominent anterio-dorsal indentation. Very small, narrow ridge at the free margins. Surface everywhere marked in a regular pattern of punctae or fine reticulations.

Dimensions of type specimen: length, .70 mm.; height, .39 mm; thickness, .30 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45159.

Remarks: This species is very close to *O. sulcatus* of the Salem formation, but is different in that *O. sulcatus* has a broad, deep furrow or sulcus closely parallel the entire posterior contact. *O. sulcatus* has a surface which is dotted with irregularly and thinly scattered punctae, whereas *O. geisi* shows a uniformly covered surface with regular arrangement of punctae. The node on *O. sulcatus* is dorsally elongate whereas on the Renault species it is nearly circular. The representatives of the genus in the Salem formation are also approximately one-third larger, the Renault specimens being less than 1 mm. in length whereas those cited by Geis from the Salem are all over 1 mm. long.

Genus Neokloedenella Croneis and Funkhouser

Neokloedenella subquadrata Croneis and Gutke, n. sp.

Plate I, fig. 10

Carapace medium sized and elongate; subrectangular to subquadrate in outline; hinge line straight or slightly convex. Dorsal view shows widening of hinge groove posteriorly. Posterior cardinal angle approximately 90°; anterior cardinal angle broadly rounded; anterior end nearly uniformly rounded; posterior end bluntly rounded; posterio-ventral swing more abrupt than anterio-ventral swing which meets the venter in a broadly rounded outline; venter nearly straight and subparalleling hingeline. Maximum height anterior; greatest thickness posterior. Surface smooth.

Dimensions of type specimen: length, .86 mm.; height, .43 mm.; thickness, .43 mm.

Locality: .0526.42 Holotype, Walker Museum, No. 45160.

Remarks: *N. subquadrata* is related to *N. prima* of the Clore formation. It is, however, much more quadrate in outline and more broadly grooved posteriorly along the hinge line.

Genus Chesterella Croneis and Gutke, n. gen.

Valve subequal, sulcate just anterior to mid-length; pit ventrad of sulcus outlined above and below by weak to strong longitudinal ridges. Surface granular, weakly pitted, or subreticulate.

Genotype: *Chesterella fissurata* Croneis and Gutke, n. sp.

Remarks: The family position of *Chesterella* is uncertain. Provisionally it is referred to the Kloedenellidae. The genus shows some vague similarities to *Kirkbyella*, however, and it may have affinities with the Kirkbyidae.

Chesterella exuta Croneis and Gutke, n. sp.

Plate I, figs. 20–21

Carapace medium size; elongate, subrectangular in outline. Hinge line slightly concave, extending nearly the full length of shell. Posterior cardinal angle approximately 100°; anterior cardinal angle approximately 140°, broadly rounded. Anterior and posterior extremities rounded, posterior outline more blunt than anterior, extremities meeting the nearly straight venter in broadly rounded swings. Two prominent depressions are located just anterior to mid-length; lower depression is a deep pit at about mid-height, upper depression is a dorsally expanding sulcus. Depression separated by flat topped ridge trending parallel hinge line. Ridge prominent at mid-carapace, gradually fading into the anterior and posterior surfaces. Less prominent lower ridge parallel to the first, bounds the subcentral pit ventrally. Ill-defined node at posterior-dorsum. Surface granular or weakly pitted.

Dimensions of type specimen: length, .80 mm.; height, .40 mm.; thickness, .37 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45161.

Remarks: *C. exuta* is more closely related to *C. fissurata* than is apparent at first glance. These common Renault species show some tendency to intergrade.

Chesterella fissurata Croneis and Gutke, n. sp.

Plate I, figs. 18–19

Carapace small, elongate, subrectangular in outline. Hinge line straight extending about 7/8 the length of the shell. Cardinal angles obtuse, anterior angle much more broadly rounded. Extremities well rounded, posterior more blunt than anterior; anterior swing meets the venter in a broadly rounded outline.

Venter slightly convex. Surface weakly reticulate, marked by three prominent nodes; posterio-dorsal node rising out of carapace to a greater height, subpointed. Anterio-dorsal node subcircular; posterio-ventral node extends toward the anterior node and is connected to it by a thin ridge that separates pit from sulcus. Posterior nodes fall off precipitously toward the posterior. Deep pit, originating near mid-carapace and trending parallel the hinge line, separates posterior nodes; shallower sulcus widens upward to the hinge line. A depression surrounds subcircular anterior node except at the narrow connecting ridge. Maximum height anterior; greatest thickness posterior. Valves subequal, right overlaps left slightly at dorso-anterior corner, and in dorsal view generally appears somewhat thicker.

Dimensions of type specimen: length, .66 mm.; height, .35 mm.; thickness, .33 mm.

Locality: .0526.42 Holotype, Walker Museum No. 45162.

Remarks: This species, which shows considerable variation, is common in the Renault.

Family Kirkbyidae Ulrich and Bassler

Genus Amphissites Girty

Amphissites grovei Croneis and Gutke, n. sp.

Plate II, figs. 28–29

Carapace subquadrate to subovate in outline, medium sized; hinge line slightly concave, marked by wide furrow extending four-fifths the length of the shell. Cardinal angles obtuse; extremities meet venter in evenly rounded outline; ventral margin slightly convex. Surface marked by three nodes; anterior node originates near mid-height, swells upward with a curvature parallel to anterior outline and terminates just above dorsal margin; posterior ridge not so prominent; made up of a long ridge-like structure originating posterio-ventrad of central node, paralleling posterior outline and ending at dorsal margin, just anterior to posterior cardinal angle; oval central node largest of the three. Deep pit located at base of central node, anterio-ventrad of its mid-point; long dimension of pit directed toward

anterior cardinal angle; small pit or scar marking located at posterio-ventrad portion of base of central node. Surface marked with fine reticulations arranged concentrically, subparalleling free edge of carapace.

Dimensions of type specimen: length, .93 mm.; height, .60 mm.; thickness, .48 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45163.

Remarks: *A. grovei* resembles *A. biforatus* of the Kinkaid formation, but it does not have a small ridge paralleling and forming the inner portion of the margin. In addition, the posterior outline in *A. biforatus* is more angular and the central node does not approach the hinge line as closely as in *A. grovei.*

Amphissites wilsoni Croneis and Gutke, n. sp.

Plate II, figs. 24–25

Carapace elongate, sub-oblong; hinge line straight or slightly concave, depressed; cardinal angles obtuse, rounded. Anterior and posterior outlines subuniformly rounded and sub-equal, joining venter smoothly; ventral margin nearly straight. In lateral view, free margin bordered by slightly elevated ridge; in ventral view, free margin bordered by narrow flange which is separated from flange on opposite valve by a conspicuous smooth area extending from angle to angle; flanges nearly equidistant from each other except for slight widening near mid-length; slope from marginal ridge to marginal flange nearly vertical so that marginal flanges are not evident in lateral view. Surface marked by three prominent nodes; elliptical node largest of the three, lies slightly posterio-dorsad to mid-point of carapace, trending slightly anterio-dorsally-posterio-ventrally. A well defined pit occurs at the anterio-ventral base of central node. Posterio-dorsal node smaller than the other two. Posterio-dorsal and anterio-dorsal nodes slope steeply toward the dorsum and toward the extremities, less abruptly toward mid-shell, and taper gently toward the venter as they merge into the general surface at about mid-height of central node; anterio-dorsal node extends slightly higher above the hinge line than does posterio-dorsal

node. In dorsal view, median node considerably more elevated than anterior node; posterior node only slightly elevated. Surface finely and regularly reticulate.

Dimensions of type specimen: length, .76 mm.; height, .43 mm.; thickness, .40 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45164.

Remarks: This species is similar to *A. bradfieldi* (new name for *A. rothi*) from the Clore formation and to *A. trilobus* from the Golconda formation. *A. wilsoni* may be distinguished from *A. bradfieldi* by its larger elliptical median node. *A. wilsoni* may be distinguished from *A. trilobus* by its elliptical median node, and by its less sharply defined posterio-dorsal node, a structure which is pointed in *A. trilobus*.

Genus Kirkbyella Coryell and Booth

Kirkbyella quadrata Croneis and Gutke, n. sp.

Plate I, fig. 12

Carapace small, suboblong in outline; hinge line straight, extending four-fifths length of specimen. Greatest length one-third shell height below dorsum; maximum height midway between center and posterior; greatest thickness near mid-length, and below mid-height. Valves equal. Posterior and anterior outlines round broadly and subequally into the venter. Slight in-curvature of ventral outline near anterior ventral quarter. Posterior cardinal angle approximately 105°, less obtuse than more rounded anterior cardinal angle. Prominent steep walled sulcus slightly anterior to mid-length, opens upward to hinge line. Longitudinal ventral elevation terminates in a turret-like node in posterio-ventral quarter. Venter grooved. Surface reticulate.

Dimensions of type specimen: length, .54 mm.; height, .27 mm.; thickness, .30 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45165.

Remarks: *K. quadrata* differs from a closely related species from the Menard formation in strength and alignment of

surface markings, in possessing a more uniform surface slope from ventral elevated area toward dorsum, and in its more quadrangular outline.

Genus Discoidella Croneis and Gale
Discoidella pendens Croneis and Gutke, n. sp.

Plate II, fig. 20

Carapace small, subelliptical; hinge line short, straight or slightly convex, grooved; cardinal angles obtuse, somewhat blunted. Valves essentially equal, right valve rising slightly above left at the hinge line. No distinguishable nodes or pits present. Greatest thickness median. Linear reticulations arranged in rows which seem to hang as pendents from the dorsal and lateral margins.

Dimensions of type specimen: length, .32 mm.; height, .36 mm.; thickness, .12 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45166.

Remarks: *D. pendens* may be distinguished from its relative, *D. simplex* of the Golconda formation by its relatively greater height and by the pendent pattern of its surface markings. The true character of the genus *Discoidella* is not yet fully understood; it may not even belong to the Ostracoda.

Family Glyptopleuridae Girty
Genus Glyptopleura Girty
Glyptopleura bristoli Croneis and Gutke, n. sp.

Plate II, figs. 3–4

Carapace medium sized, subquadrate to subovate in outline. Hinge line straight for the anterior two-thirds of length but rising in the posterior third. Posterior cardinal angle obtuse but much more abrupt than anterior angle which is broadly rounded. Greatest thickness and height posterior to mid-carapace. Individuals broadly wedge-shaped when viewed from above. Surface marked by seven unequal sub-parallel longitudinal ridges; top and bottom ridges form a broad "U", whose base follows

roughly the configuration of anterior outline; "U" open at posterior. Upper minor ridge extends posteriorly less the one-half length of shell, possesses a branch extending diagonally upward and backward to hinge line at anterio-dorsal corner. Between bounding ridges are five major ribs, the three ventral ribs and the one immediately below the upper ridge join the "U" anteriorly; the third rib, from the top, fails to join the "U". The two lower ventral ridges split near mid-length but join again a little posterior to mid-length and continue on posteriorly to meet fifth rib; two short hooked ridges extend from the lower ridge toward the venter about at mid-length. Superimposed upon the posterior swelling is a short, broken rib which lies between the second and third dorsal ribs. Anterior to this broken rib is a pit situated just above the central part of the shell. The three dorsal ridges trend obliquely downward posterior to anterior; the four ventral ones are irregularly sub-parallel to the hinge line. Vague anterior marginal ridge. Surface reticulated.

Dimensions of type specimen: length, .99 mm.; height, .54 mm.; thickness, .63 mm.

Locality: .0526.42 Holotype, Walker Museum, No. 45167.

Remarks: *G. bristoli* is a close relative of the associated *G. pergibba* and of *G. gibba* of the Golconda formation, the general rib arrangement of all three species being very similar. The posterior convexity of the hinge line in *G. bristoli* is, however, a distinctive feature, and this, together with its broken posterior dorsal rib will serve to distinguish it. The surface of *G. bristoli*, like that of *G. pergibba*, shows some pitting or reticulations, but the feature is less well expressed than in the latter species.

Glyptopleura elliptica Croneis and Gutke, n. sp.

Plate II, fig. 9

Carapace small to medium sized, subquadrate to subovate in outline; hinge line straight or slightly incurved near mid-dorsum. Anterior cardinal angle obtuse, and somewhat more abrupt than more broadly rounded posterior angle. Anterior and posterior outlines broadly and subuniformly rounded, meeting the slightly

convex venter with subequal curvature. Maximum height near mid-shell; greatest thickness half way between posterior extremity and mid-length of valve. Surface marked by five sub-parallel longitudinal ridges which are also sub-parallel the dorsum; dorsal and ventral ridges meet both anteriorly and posteriorly and more or less conform to the configuration of the shell outline. Prominent second and fourth ridges which are slightly convex toward the implanted rib, join in rounded outline posteriorly, and meet weaker upper and lower ridges anteriorly. Relatively straight major ridge implanted between second and fourth ridges fails to meet the others. Second major rib with a marked ventral deflection in the dorso-anterior quarter. There is a minor ventral ridge below the continuous ventral rib structure. Pit lies immediately above the central ridge and slightly anterior to mid-length.

Dimensions of type specimen: length, .75 mm.; height, .42 mm.; thickness, .37 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45168.

Remarks: *G. elliptica* is similar to *G. conflexacosta* of the Golconda formation and may well be ancestral to that species. In that form, however, the sub-marginal ridge is not continuous, the second and fourth major ribs are not convex toward mid-carapace, and they are much more extended posteriorly. *G. elliptica* is similar to a long line of later Chester glyptopleurids, including not only Golconda, but Vienna, Clore, and probably Kinkaid types. It is also related to *G. schizopleura* Coryell and Sohn of the Reynolds formation of West Virginia.

Glyplopleura henbesti Croneis and Gutke, n. sp.

Plate II, figs. 7–8

Carapace medium sized, subquadrate to subovate in outline. Hinge line straight or slightly concave. Cardinal angles approximately 125 degrees, rather abrupt. Greatest thickness posterior to mid-carapace; maximum height anterior. Individuals wedge shaped when viewed from above, posterior ter-

mination pointed. Surface marked by seven unequal sub-parallel ridges; top and bottom ridges form a broad "U", whose base follows roughly the configuration of anterior outline; "U" open at posterior. Top ridge originates anterio-dorsally. Between bounding ridges are five major ribs; the three ventral ribs and the one immediately below the upper ridge, join the "U" anteriorly; the third rib slopes from posterior to anterior and fails to join the "U". Third rib above venter joins the lower ridge at the posterio-ventrally to form a short single posterior rib extension; second rib from venter fails to meet the other ventral ribs, terminating at mid-venter. Pit located near mid-length just below the longest dorsal rib. Extremities meet a slightly convex venter in broad swings, posterior more broadly rounded than anterior. Dorsal posterior border marked by minute spines. Marginal ridge extending from anterio-dorsal area to mid-venter. Surface marked by vague, irregular reticulations.

Dimensions of type specimen: length, .86 mm.; height, .50 mm.; thickness, .53 mm.

Locality: .0526.42 Holotype, Walker Museum, No. 45169.

Remarks: *G. henbesti* is a close relative of the associated *G. hendricksi*, but it has a larger unribbed posterior area, is more rounded in outline, and is differently marked in the anterior dorsal quarter.

Glyptopleura hendricksi Croneis and Gutke, n. sp.

Plate II, figs. 5–6

Carapace medium sized, subquadrate to subovate in outline. Hinge line straight or slightly convex. Posterior cardinal angle obtuse but much more abrupt than anterior angle which is rounded. Extremities meet the slightly convex venter in broad subequal swings. Greatest thickness and height posterior to mid-carapace. Individuals wedge shaped, and posteriorly pointed when viewed from above. Surface marked by subparallel ridges; top and bottom ridges form a broad "U" whose base follows roughly the configuration of anterior outline; "U" open at posterior. Top ridge originates in anterio-dorsal area.

Two small ribs oriented at right angles to each other located anterio-dorsal district just above the two major dorsal ribs. Between bounding ridges are five major ribs; the three ventral ridges and the second dorsal rib join the "U" anteriorly; third rib, sloping posterior to anterior, fails to join the "U". The two ventral ribs join near venter near median line. Ridge originating at the anterio-cardinal angle follows close to the anterior margin, and terminates in the anterio-ventral quarter. Flange on anterior and ventral margins. Surface marked by vague irregular reticulations. Posterior dorsal border marked by minute spines.

Dimensions of type specimen: length, .90 mm.; height, .53 mm.; thickness, .43 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45170.

Remarks: *G. hendricksi* is most closely related to the associated *G. pergibba*, especially in the character and alignment of the surface markings. It is, however, a less obese, and more ovate species whose ribs are different in detail from those of *G. pergibba*.

Glyptopleura pergibba Croneis and Gutke, n. sp.

Plate II, figs. 1–2

Carapace medium sized, subquadrate to subrhomboidal in outline. Hinge line straight to slightly concave. Posterior cardinal angle approximately 90°, anterior angle obtuse, approximately 125°. Anterior outline only slightly convex; posterior outline straight for the most part, but rounding less abruptly into venter than at the anterior; ventral margin straight or slightly convex and irregularly parallel the hinge line. Ridge along ventral margin. Maximum height anterior, greatest thickness slightly posterior to mid-length. Dorsal view arrowhead-like in outline. Surface marked by five major sub-parallel irregular longitudinal ridges. The major upper ridge, broken posteriorly, meets the bottom one anteriorly to form a "U", whose base and lower arm follow the configuration of the anterior and ventral outlines; posterior portion of the "U" open. Two

top ridges trend obliquely downward from posterior to anterior, three bottom ones irregularly parallel hinge line. Lower ridge split anterior to mid-length of the shell, but unites again posterior to mid-length. Two lower ridges meet posteriorly. Central ridge nearly as long as shell, meets the "U" anteriorly. Small node-like swelling in dorso-anterior quarter above upper ridge, which is also characterized by an upward trending branch of the major dorsal ridge extending toward the anterior cardinal angle. Deep pit between two upper ridges near center of shell. Faint reticulations on shell.

Dimensions of type specimen: length, .78 mm.; height .53 mm.; thickness, .51 mm.

Locality: .0526.42 Holotype, Walker Museum, No. 45171.

Remarks: *G. pergibba* is a close relative of *G. gibba* of the Golconda formation, but it is much more quadrate in outline and proportionately even more obese. In addition its ridges, although similar in kind, are different in placement and detail, especially in the ventral and posterior areas. The very definite surface pitting is a feature unusual in this genus.

Genus Glyptopleurina Coryell

Glyptopleurina coryelli Croneis and Gutke, n. sp.

Plate II, figs. 21–22

Carapace medium sized, sub-oblong to sub-ovate in outline; essentially equivalved, but left valve probably slightly larger than right. Hinge line straight or slightly convex, extending about three-fifths length of shell. Maximum height anterior; greatest thickness posterior to mid-length. Anterior outline more broadly rounded than posterior; both ventral swings regularly rounded; venter nearly straight in mid-section, but extended into a broadly rounded posterior swing. Cardinal angles roundly and sub-equally obtuse. Surface marked with two ridges and two sub-central dorsal nodes, of which the anterior is the more conspicuous. The nodes are separated by a pit just anterio-dorsad of mid-carapace. The upper and smaller of the two ridges originates at the base of the posterior node and runs obliquely

downward and forward to its abrupt anterior termination just below the anterior node. The lower ridge begins in the anterio-dorsal quarter, and follows the general configuration of the anterio-ventral outline well into the anterio-ventral quarter where it changes direction and extends backward below and sub-parallel to the shorter, higher ridge, terminating below and somewhat behind posterior node. Indistinct ridge extends around free margins.

Dimensions of type specimen: length, .75 mm.; height, .45 mm.; thickness, .36 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45172.

Remarks: *Glyptopleurina coryelli* is a close relative of, and may be ancestral to *G. ? bulbosa* of the Golconda formation, but the latter species has venter and dorsum much more nearly parallel and it is more quadrate in appearance. The surface markings of the Golconda species also are more complex, and its ridges more nearly parallel than in *G. coryelli.*

Because of the position of greatest shell thickness we have oriented the Chester representatives of this genus in reverse as compared with the orientation given by Coryell for the genotype, *G. montifera,* from the Pennsylvanian Boggy shale.

Glyptopleurina simulans Croneis and Gutke, n. sp.

Plate II, figs. 13–14

Carapace medium sized, sub-oblong to sub-ovate in outline; right valve larger at the free margins. Hinge line straight or slightly convex, extending about three-fourths the length of shell. Maximum height anterior; greatest thickness posterior. Anterior outline slightly angular near mid-height; posterior outline more rounded, venter nearly straight in mid-section, but extended into broadly rounded swings both anteriorly and posteriorly. Cardinal angles roundly and subequally obtuse. Node located in anterio-dorsal quarter; pronounced sulcus immediately posterior to node. Surface marked by two ridges; the upper and smaller ridge originates at the base of the node and extends ob-

liquely upward, terminating just posterior to the sulcus. The lower ridge begins below the place of origin of the smaller ridge and follows the configuration of the ventral and posterior outlines, then it changes direction in the posterio-dorsal quarter and extends backward sub-parallel to the hinge line and terminates at the sulcus. Dorsal view wedge shaped, and shows right valve overlapping left both posteriorly and anteriorly; wide furrow down hinge line, widest near mid-length. Surface finely reticulated. Indistinct ridge on left valve along free margin.

Dimensions of type specimen: length, .83 mm.; height, .50 mm.; thickness, .46 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45173.

Remarks: *G. simulans* is vaguely similar to the associated *G. coryelli* in lateral view, but the dorsal expression of the two species is very different. Some of the glyptopleurine forms from the Menard formation are also superficially like *G. simulans*.

Genus Glyptopleuroides Croneis and Gale

Glyptopleuroides girtyi Croneis and Gutke, n. sp.

Plate II, figs. 11–12

Carapace small to medium sized; elongate, subquadrate in outline; hinge line straight, very slightly depressed. Maximum height and greatest thickness somewhat behind mid-line. Posterior cardinal angle sharp, approximately 95°; anterior cardinal angle approximately 135°, bluntly rounded. Anterior outline steep, projecting forward from cardinal angle to point about one-third shell height above venter, from which it rounds smoothly into venter; posterior outline blunt, rounding abruptly into venter. Ventral and dorsal areas broad, flattened. A major groove beginning slightly posterior to anterior cardinal angle on dorsum, swings around the anterior end rising obliquely upward to slightly below the mid-height at mid-length, continuing subparallel the hinge line, terminating at a pronounced ridge paralleling the posterior edge and located just anterior to posterior margin. Minor groove originating at point of termination of

major groove, trends obliquely toward the venter, terminating slightly anterior of mid-venter. More or less vertical groove located anteriorly adjacent to pronounced posterior ridge. Dorsal half of shell heavily pitted with broken elongated grooves sub-paralleling the hinge line. Flange at posterior margin.

Dimensions of type specimen: length, .72 mm.; height, .36 mm.; thickness, .33 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45174.

Remarks: *G. girtyi* is a close relative of *G. insculptus* of the Golconda formation. The former, however, is somewhat thicker, and its position of greatest height lies considerably posterior to that in the latter. More important, the surface marking of the Renault species are much less linear than those in *G. insculptus*, especially in the posterior-dorsal quarter, where *G. girtyi* is much more pitted.

Glyptopleuroides perplexa Croneis and Gutke, n. sp.

Plate II, figs. 18–19

Carapace small, subquadrate in outline; hinge line straight, long, slightly depressed. Maximum height median; greatest thickness midway between center and posterior extremity. Posterior and anterior outlines sub-equally rounded. Cardinal angles sub-equally obtuse; posterior angle somewhat more acute than slightly rounded anterior angle. Anterior and posterior outlines round sub-uniformily into the venter which is nearly straight and sub-parallel the hinge line. Venter and dorsum broad and deeply grooved longitudinally. Surface irregularly marked by deep grooves with broad flat topped ridges between. A major groove, beginning slightly posterior to anterior cardinal angle, swings around the anterior end slightly posterior to the anterior margin to the anterio-ventral quarter, where it trends abruptly upward for a short distance and then roughly parallels the hinge line, terminating slightly anterior to a transverse groove in the posterior section. Major groove beginning in posterio-dorsal quarter trends obliquely downward and forward

through mid-point of shell, terminating just posterior to transverse anterior groove. Prominent groove trending obliquely downward, posterior to anterior in anterio-dorsal quarter, originating near hinge line and terminating at transverse anterior groove slightly below mid-height. Mid-dorsal section heavily pitted. Prominent ridge originating at hinge line, located slightly anterior of posterior outline, follows configuration of posterior margin, and fades into the venter at the posterio-ventral corner.

Dimensions of type specimen: length, .72 mm.; height, .42 mm.; thickness, .36 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45175.

Remarks: *G. perplexa* is a close relative of the associated *G. girtyi* and of *G. insculptus* of the Golconda formation. The former is, however, of somewhat greater height, is more quadrate in outline, and differently marked. *G. perplexa* is also much more symmetrical than *G. insculptus*. The Renault form is much more heavily pitted than the Golconda species, and carries a more prominent transverse ridge near the posterior margin.

Family Bairdiidae Sars
Genus Bairdia McCoy
Bairdia golcondensis Croneis and Gale

Plate II, fig. 23

Bairdia golcondensis Croneis and Gale, New Ostracodes from the Golconda Formation, Den. Univ. Bull., Jour. Sci. Labs., 33, 286, pl. VI, figs. 26–27 (1938).

Dimensions of figured specimen: length, .90 mm.; height, .50 mm.; thickness, .30 mm.

Locality: .0905.52D Hypotype, Walker Museum, No. 45176.

Remarks: *B. golcondensis* is not uncommon in the Renault formation. The specimen figured in this paper is slightly larger than the holotype, but its proportions are almost identical.

Bairdia mccoyi Croneis and Gutke, n. sp.

Plate II, fig. 15

Carapace large, elongate, subrhomboidal in outline. Valves unequal. Length approximately two and one-half times the height. Maximum height slightly posterior to mid-shell; greatest thickness slightly anterior to mid-length. Left valve overlaps right, most prominently along dorsal margin especially at mid-dorsum; fairly strong overlap along venter; posterior extremity bluntly pointed; anterior outline bluntly rounded and meeting the dorsum at an angle not greatly in excess of 90°. Dorsal outline elevated and broadly rounded somewhat angular where it joins dorso-posterior slope which is steep and straight above, markedly concave below; slope to anterior extremity long, gentle and concave near anterior beak. Ventral margin broadly concave anterior to mid-length; posterio-ventral slope nearly straight except where it swings abruptly upward into the posterior beak. Anterio-ventral slope regularly and broadly rounded. Surface smooth.

Dimensions of type specimen: length, 1.56 mm.; height, .63 mm.; thickness, .48 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45177.

Remarks: *Bairdia mccoyi* is similar to *B. renaultenis*, but is more quadrate in outline, has a more prominent dorsal overlap, and a less pronounced and more anteriorly placed ventral concavity.

Bairdia renaultensis Croneis and Gutke, n. sp.

Plate I, figs. 5–6

Carapace large; length two and one-half times the height. Valves unequal; left overlapping right subequally on all margins, but with dorsal overlap somewhat the strongest. Venter more or less straight, except for a concavity mid-length, becoming slightly convex near extremities. Anterior ventral slope with abruptly rounded backward swing into venter; posterior bluntly pointed, posterio-ventral slope gentle, only slightly convex. Anterio-

dorsal slope concave; posterio-dorsal slope more prominently incurved; dorsal outline broadly rounded, but falling away most rapidly toward posterior. Surface smooth. Dorsal view shows posterior and anterior extremities tapering sub-equally with greatest thickness subcentral.

Dimensions of type specimen: length, 1.2 mm.; height, .48 mm.; thickness, .36 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45178.

Remarks: In lateral view *B. renaultensis* resembles the conventional outline of an admiral's hat. Due to a small break in the carapace the type specimen shows a slightly greater mid-ventral concavity than is typical for the species.

Genus Macrocypris Brady

Macrocypris biconcava Croneis and Gutke, n. sp.

Plate I, figs. 16–17

Carapace small, elongate, sub-triangular in outline. Venter nearly straight, slightly concave in midsection. Anterior extremity sharp, narrowly rounded; posterior extremity rather sharply rounded, pointed in dorsal views. Dorsal outline sub-uniformly rounded from posterior extremity to well defined anterior cardinal angle. Slope from anterior cardinal angle to anterior beak concave. Maximum height somewhat posterior to mid-carapace; greatest thickness near mid-shell, possibly slightly posterior; greatest length near venter. Right valve overlaps left valve. Surface smooth.

Dimensions of type specimen: length, .63 mm.; height, .27 mm.; thickness, .30 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45179.

Remarks: *M. biconcava* is a common species in the Renault formation.

Genus Hastacypris Croneis and Gutke, n. gen.

Carapace hastate in outline, more acuminate end posterior, greatest thickness behind mid-line; dorsal overlap of right valve pronounced; dorsum sub-regularly convex, venter straight or slightly convex.

Genotype: *Hastacypris bradyi* Croneis and Gutke, n. sp.

Remarks: Similar to *Bythocypris*, but right valve larger than the left; like *Macrocypris*, but no overlap on venter; venter convex or straight, not concave; much more pointed posteriorly; more angulated outline anteriorly.

Hastacypris bradyi Croneis and Gutke, n. sp.

Plate II, figs. 16–17

Carapace large, elongate, subtriangular in outline; length about three times the height. Valves unequal; right valve overlapping left on dorsal margin from sharply pointed posterior beak almost to anterior-dorso angle. Dorsal outline broadly and subuniformly rounded; venter notably less convex, straight or very possibly slightly concave in the posterior quarter. Posterior extremity pointed; anterior outline more or less straight, extending obliquely downward and backward from dorso-anterior angle toward venter. Maximum height sub-central; maximum thickness posterior to mid-line; surface smooth.

Dimensions of type specimen: length, 1.32 mm.; height, .39 mm; thickness, .26 mm.

Locality: .0905.52D Holotype, Walker Museum, No. 45180.

Remarks: This striking species is distinguished by its extreme length, its hastate posterior, its pronounced dorsal overlap, especially in the posterior quarter, and by its straight, backward trending, anterior outline.

Family Cytherellidae Sars

Genus Cavellina Coryell

Cavellina spatulata Croneis and Gutke, n. sp.

Plate I, fig. 2

Carapace large, subovate in outline; right valve overlaps left completely, most prominently along dorsum, less markedly at the venter, least at the ends. Hinge line convex. Posterio-dorsal slope much longer and more gently sloping than anterio-dorsal slope; posterio-dorsal slope straight or slightly convex, anterio-dorsal slope broadly rounded. Posterior end much more

sharply rounded than anterior outline. Extremities meet a straight or slightly convex venter in equally rounded swings. Maximum height slightly anterior of vertical median line; greatest thickness just posterior to middle. Surface evenly convex and smooth.

Dimensions of type specimen: length, 1.15 mm.; height, .80 mm.; thickness, .60 mm.

Locality: .0526.42 Holotype, Walker Museum, No. 45181.

Remarks: The general outline of this species appears to be reversed to Coryell's original description of *Cavellina*. However, the orientation has been based on the right valve overlapping the left and the thickest part being posterior. *C. spatulata* is the most expanded anteriorly of the representatives of the genus in our collections. It is also notably obese posteriorly.

Cavellina parallela Croneis and Gutke, n. sp.

Plate I, fig. 1

Carapace medium sized, subreniform, elongate. Hinge line essentially straight to convex; right valve dorsal outline arched; anterior and posterior outlines rounded, the former more uniformly so, posterior dorsal outline nearly straight. Right valve larger than left and overlaps it completely. Greatest overlap dorsal where right valve outline is arched considerably above hingement, especially in front; venter shows next smaller overlap; the overlap at the anterior outline is intermediate between that shown on venter and at posterior, where smallest amount is seen. The left valve outline follows closely that of right valve except at dorsum where it is very broadly triangular instead of broadly arched. Greatest height at mid-length and near point of greatest dorsal convexity. Dorsal view shows specimen to be nearly equally inflated in all areas from anterior to posterior, the surface rounding off abruptly near the margins. Venter essentially straight, slightly concave. Surface smooth.

Dimensions of type specimen: length, 1.10 mm.; height, .63 mm.; thickness, .26 mm.

Locality: .0526.41 P29.Q Holotype, Walker Museum, No. 45182.

Remarks: *C. parallela* may be distinguished from its relatives on the basis of its regular outline and the essentially parallel flattened shell surfaces.

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NEW OSTRACODES FROM THE RENAULT FORMATION

Explanation of Plate I

(All magnifications are accurate to within 4 percent)

Fig. 1. *Cavellina parallela* Croneis and Gutke, n. sp.; left valve, × 30.

Fig. 2. *Cavellina spatulata* Croneis and Gutke, n. sp.; left valve, × 30.

Figs. 3–4. *Perprimitia elegans* Croneis and Gutke, n. sp.; fig. 3, right valve, × 30; fig. 4, dorsal view, × 30.

Figs. 5–6. *Bairdia renaultensis* Croneis and Gutke, n. sp.; fig. 5, right valve, × 30; fig. 6, dorsal view, × 30.

Figs. 7–9. *Pterocodella inconsueta* Croneis and Gutke, n. sp.; fig. 7, right valve, × 50; fig. 8, dorsal view, × 50; fig. 9, another specimen tentatively referred to this species.

Fig. 10. *Neokloedenella subquadrata* Croneis and Gutke, n. sp.; left valve, × 30.

Fig. 11. *Paraparchites robustus* Croneis and Gutke, n. sp.; right valve, × 30.

Fig. 12. *Kirkbyella quadrata* Croneis and Gutke, n. sp.; left valve, × 50.

Fig. 13. *Paraparchites inornatus* (McCoy), left valve, × 30.

Figs. 14–15. *Jonesina holli* Croneis and Gutke, n. sp.; fig. 14, right valve, × 30; fig. 15, dorsal view, × 30.

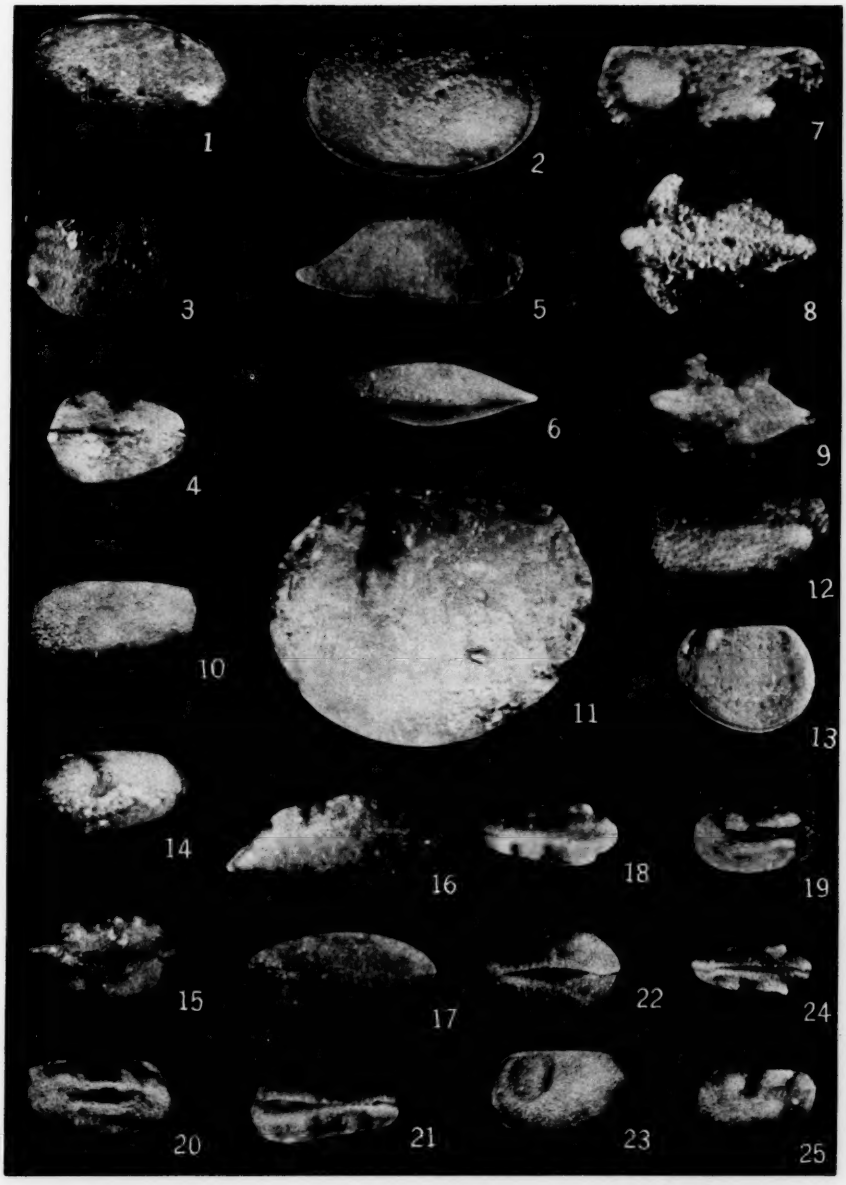
Figs. 16–17. *Macrocypris biconcava* Croneis and Gutke, n. sp.; fig. 16, left valve, × 50; fig. 17, dorsal view, × 50.

Figs. 18–19. *Chesterella fissurata* Croneis and Gutke, n. gen.; n. sp.; fig. 18, dorsal view, × 30; fig. 19 left valve, × 30.

Figs. 20–21. *Chesterella exuta* Croneis and Gutke, n. gen., n. sp.; fig. 20, right valve, × 30; fig. 21, dorsal view, × 30.

Figs. 22–23. *Jonesina wrighti* Croneis and Gutke, n. sp.; fig. 22, dorsal view, × 30; fig. 23, left valve, × 30.

Figs. 24–25. *Perprimitia turrita* Croneis and Gutke, n. sp.; fig. 24, dorsal view, × 30; fig. 25, left valve, × 30.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Explanation of Plate II

(All magnifications are accurate to within 4 percent)

Figs. 1–2. *Glyptopleura pergibba* Croneis and Gutke, n. sp.; fig. 1, right valve, × 30; fig. 2, dorsal view, × 30.

Figs. 3–4. *Glyptopleura bristoli* Croneis and Gutke, n. sp.; fig. 3, right valve, × 30; fig. 4, dorsal view, × 30.

Figs. 5–6. *Glyptopleura hendricksi* Croneis and Gutke, n. sp.; fig. 5, left valve, × 30; fig. 6, dorsal view, × 30.

Figs. 7–8. *Glyptopleura henbesti* Croneis and Gutke, n. sp.; fig. 7, right valve, × 30; fig. 8, dorsal view, × 30.

Fig. 9. *Glyptopleura elliptica* Croneis and Gutke, n. sp.; right valve, × 30.

Fig. 10. *Oliganisus geisi* Croneis and Gutke, n. sp.; left valve, × 30.

Figs. 11–12. *Glyptopleuroides girtyi* Croneis and Gutke, n. sp.; fig. 11, right valve, × 30; fig. 12, dorsal view, × 30.

Figs. 13–14. *Glyptopleurina simulans* Croneis and Gutke, n. sp.; fig. 13, left valve, × 30; fig. 14, dorsal view, × 30.

Fig. 15. *Bairdia mccoyi* Croneis and Gutke, n. sp.; right valve, × 30.

Figs. 16–17. *Hastacypris bradyi* Croneis and Gutke, n. gen., n. sp.; fig. 16, left valve, × 30; fig. 17, dorsal view, × 30.

Figs. 18–19. *Glyptopleuroides perplexa* Croneis and Gutke, n. sp.; fig. 18, left valve, × 30; fig. 19, dorsal view, × 30.

Fig. 20. *Discoidella pendens* Croneis and Gutke, n. sp.; left valve, × 50.

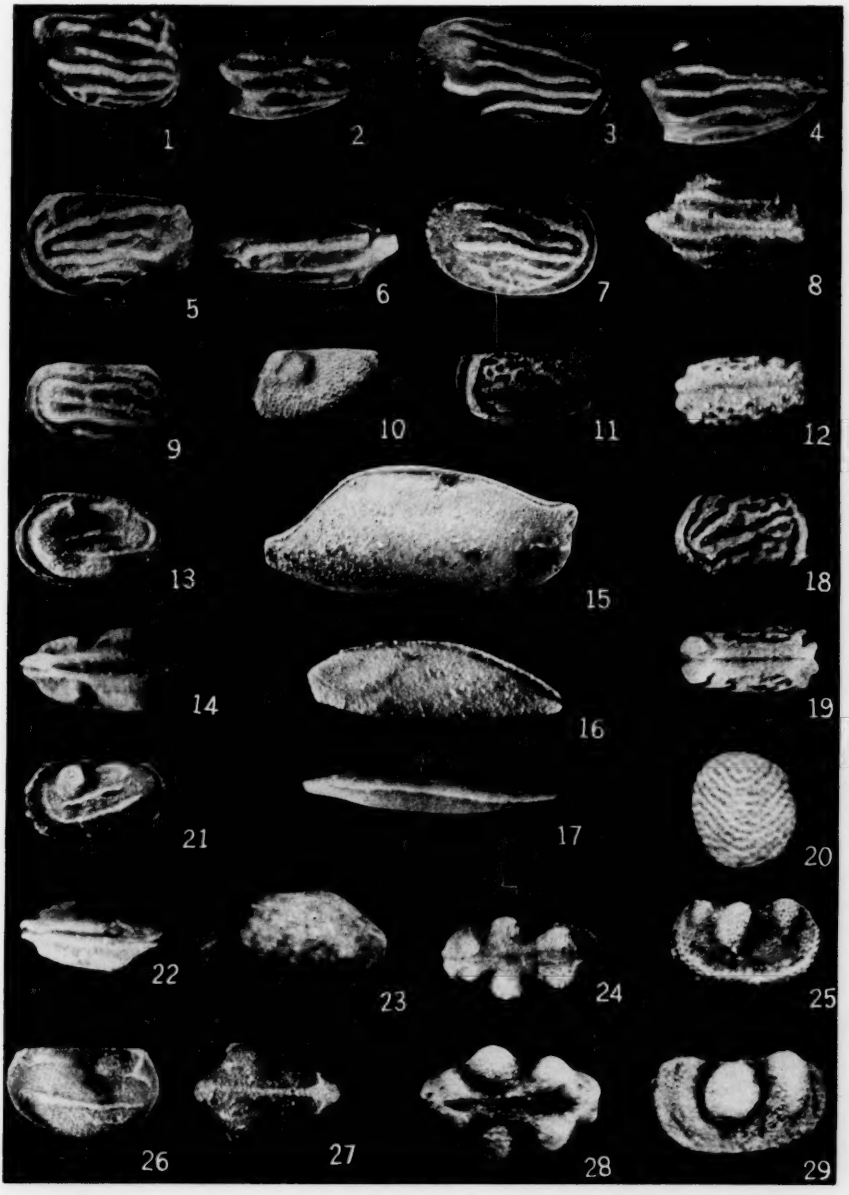
Figs. 21–22. *Glyptopleurina coryelli* Croneis and Gutke, n. sp.; fig. 21, left valve, × 30; fig. 22, dorsal view, × 30.

Fig. 23. *Bairdia golcondensis* Croneis and Gale, right valve, × 30.

Figs. 24–25. *Amphissites wilsoni* Croneis and Gutke, n. sp.; fig. 24, dorsal view, × 30; fig. 25, right valve, × 30.

Figs. 26–27. *Knoxina rogatzi* Croneis and Gutke, n. sp.; fig. 26, right valve, × 30; fig. 27, dorsal view, × 30.

Figs. 28–29. *Amphissites grovei* Croneis and Gutke, n. sp.; fig. 28, dorsal view, × 30; fig. 29, right valve, × 30.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